STATE OF CALIFORNIA
DMV
DEPARTMENT OF MOTOR VEHICLES

VISION TESTING OF RENEWAL APPLICANTS: CRASHES PREDICTED WHEN COMPENSATION FOR IMPAIRMENT IS INADEQUATE

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June 1995

Research and Development Section
Division of Program and Policy Administration
California Department of Motor Vehicles
RSS-95-152

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE June 1995	3. REPORT TYPE AND DATES COVERED	
4. TITLE AND SUBTITLE Vision Testing of Renewal Applicants: Crashes Predicted when Compensation for Impairment is Inadequate			5. FUNDING NUMBERS
6. AUTHOR(S) David F. Hennessy			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) California Department of Motor Vehicles Research and Development Section 2415 1st Avenue Sacramento, CA 95818			8. PERFORMING ORGANIZATION REPORT NUMBER RSS-95-152
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT			12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This study addresses the enhanced vision test system component of a departmental plan to increase the competency level of the California driving population. Five experimental vision tests were administered to 3,669 randomly selected Class C renewal applicants in three field offices. The objective was to identify the vision tests showing the most promise for further validation in a large-scale statewide study. Hierarchical multiple regression analyses indicated that the relationship between vision test scores and crash involvement varies depending on applicant's age, general visual ability, and reported level of self-restriction. It was recommended that (1) management consider referring all DMV Snellen test fails to a vision specialist through the DL 62 process, (2) cross-validate the most promising tests (Pelli-Robson low-contrast acuity and perceptual reaction time assessment) in a large-scale demonstration project, and (3) continue research on developing improved assessment tests and protocols for drivers with age-related impairments.

14. SUBJECT TERMS			15. NUMBER OF PAGES 67
vision tests, vision screening, driver screening, elderly drivers, age-related disabilities, self-restriction, compensation, visually impaired drivers, driving competency			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (2-89)
Prescribed by ANSI Std. Z39-18
298-102

PREFACE

This study represents the component of the department's driver competency enhancement program calling for an enhanced vision test system. The effort is a follow-up to a 1990 study by Dr. Barbara Steinman of the Smith-Kettlewell Eye Research Institute, which the department commissioned as part of the research fellowship program. Also included in this study was a visual attention test developed by Drs. Karlene Ball and Cynthia Owsley. This test was selected for inclusion due to a series of empirical studies showing it to have promise in discriminating between crash-free and crash-involved older drivers.

The present report is being issued as an internal technical monograph of the Department of Motor Vehicles' Research and Development Section rather than an official report of the State of California. The findings and opinions may therefore not represent the views and policies of the State of California.

ACKNOWLEDGMENTS

This study was designed and conducted under the general direction of Raymond C. Peck, Research Chief and the supervision of Robert Hagge, Research Manager. Both Mr. Peck and Mr. Hagge made especially valuable contributions in their reviews of the final report. Dr. Mary Janke, Research Scientist, also contributed to the study design and offered comments on drafts of the final report.

The Smith-Kettlewell Eye Research Institute (SKERI), represented by Dr. John Brabyn, provided a consultant, prototype Smith-Kettlewell Low Luminance Cards, and a Berkeley Glare Tester. The SKERI consultant, Dr. Gunilla Haegerstrom-Portnoy, developed written step-by-step protocol for administering and scoring five of the six prototype vision tests, trained the field-office testing-personnel in administering the vision tests, and made sure the vision tests were administered under the proper lighting conditions.

Synemed, Inc., represented by Neal Compton, provided the Optifield II automated perimeter and programmed it to run in accordance with testing protocol specifications developed by Dr. Haegerstrom-Portnoy.

Visual Resources, Inc., represented by H. Michael Lewellen, provided a Visual Attention Analyzer machine and Useful Field Of View (UFOV) software. Dr. Karlene Ball served as a consultant in administration of the UFOV test.

Doris Macmurphy, Region III Manager and Norma Peters Region II acting Manager made available the field office staff and space needed for the study.

Pilot testing was carried out in the South Sacramento Field office. Fine tuning of the study protocol was greatly facilitated by Linda Grimshaw, the Field Office Manager, Florence Payne, the Operations Officer, and Elaine Miller, the Driver License Supervisor.

Special thanks go to Maria Vasquez-Diaz and Gayle Tracy, the Motor Vehicle Field Representatives who administered different versions of the testing protocol and helped with its modification.

Data were collected at the Carmichael, El Cerrito, and Roseville field offices. Field Office Managers Rosemarie Dunbar, Tanya Little, and Lynette Purvis, Operations Officers Pat Boone, Doris Stewart, and Louise Martinez, and Driver License Managers/Supervisors Kathy Majesky, Tracy Bowman, and Jake Arellano all facilitated the completion of the study. Exceptional contributions were made to the success of this study by all the Motor Vehicle Field Representatives that recruited and tested the study subjects: Jake Arellano II, Jan Swensen, Lisa Zwicky, Karen Defreitas, Felicia Alexander-Harry, Mary Williams, Louiz Elvira, Mary Giusti, Eloise Ward, and Pat Green.

The transfer of test and survey data from hardcopy to tape was performed by Headquarters Operations' Data Entry, under the direction of Joanne Lopez, Data Entry Manager.

Assistance in extracting driver record data was provided by Michael Gebers, Research Analyst and Alan Fung, EDP Programmer. Darci Neves, Office Technician, assisted in summarizing the survey data.

Douglas Luong, Office Technician, assisted in typing the report. Debbie McKenzie, Staff Services Analyst, prepared the graphs and formatted the final report.

EXECUTIVE SUMMARY

Objective

This study assessed the utility of five experimental vision tests. The evaluation represents one component of a comprehensive California Department of Motor Vehicles (DMV) program aimed at increasing the competency level of the California driving population.

Experimental Vision Tests

- **Pelli-Robson Low-Contrast Acuity Test**–measures loss in low-contrast acuity (ability to see objects and borders).
- **Smith-Kettlewell Low-Luminance Card**–measures high-contrast near-acuity loss and low-contrast near-acuity loss.
- **Berkeley Glare Tester**–measures low-contrast near-acuity loss, and low-contrast near-acuity loss in the presence of glare.
- **Modified Synemed Perimeter**–measures standard visual field-integrity loss and attentional visual field-integrity loss.
- **Visual Attention Analyzer**–measures loss in useful field of view (UFOV), the area of the visual field in which useful information can be rapidly extracted from a complex visual display. This study evaluated total UFOV loss, UFOV loss associated

with divided attention (UFOV-DA), and the estimate of the subject's perceptual reaction time (PRT) made by the Visual Attention Analyzer.

Study Questions

1. How did the study subjects rate the six experimental vision tests? Do the different vision tests evidence face validity?
2. Is vision test performance (VTP) by itself predictive of crashes for all age groups combined?
3. How does performance on the department's Snellen test and the experimental vision tests vary with age?
4. Is VTP by itself predictive of crashes for certain age groups?
5. Is VTP predictive of crashes for all age groups combined after statistically adjusting for differences in crash involvement due to differences in gender, age, and amount of exposure?
6. Is VTP more predictive of crashes for certain age groups after statistically adjusting within each age group for gender, age, and amount of exposure?
7. To what extent do poor-vision drivers and older drivers self-restrict? How does the magnitude of self-restriction vary with VTP and age?
8. Is the relationship between VTP and crashes moderated (mediated) by self-restriction?
9. Is there any evidence of other variables moderating (mediating) the relationship between VTP and crashes?
10. What are the operational and policy implications of the results?

Methods

Data collection. The experimental vision tests and a driving habits survey form were administered to a total of 3,669 randomly selected Class C license renewal applicants in the Carmichael, El Cerrito, and Roseville field offices from February through October 1992. To participate in the study, an applicant must have been a California licensed driver for at least 12 years and not been able to renew their license by mail. Immediately after each vision test, the subject was administered a brief customer reaction survey. The renewal applicant was then administered the department's Snellen test as it is usually done and the result was recorded on the subject's score sheet.

Data analysis. Performance on each experimental test was evaluated for its association with the number of crash involvements occurring during the 3 years prior to testing. Correlational and hierarchical multiple regression techniques were used to assess the relationship between vision test scores and crashes both before and after adjusting for covariation with other variables such as age and exposure.

Results

Study question 1: How did the study subjects rate the six experimental vision tests? Do the different vision tests evidence face validity?

- Subjects rated all five vision tests very positively on clarity of instructions.

- The Pelli-Robson low-contrast acuity test, the Smith-Kettlewell Low-Luminance Card, the Berkeley Glare Tester, and the Modified Synemed Perimeter test of standard field-integrity loss were rated highly on the safety-relatedness of the tested sensory abilities and on the fairness of possibly using test results for making licensing decisions.
- Subjects tended to be less certain about the safety-relatedness and fairness of the Modified Synemed Perimeter test of attentional field-integrity loss and the Visual Attention Analyzer test.

<u>Study question 2</u>: Is VTP by itself predictive of crashes for all age groups combined?

- None of the vision test scores were significantly associated with total prior 3-year crash involvement for all age groups combined.

<u>Study question 3</u>: How does performance on the department's Snellen test and the experimental vision tests vary with age?

- Performance on the vision tests tended to get worse with increasing age.
- Age-group differences in acuity scores were greatly accentuated when contrast and luminance were reduced, as were age-group differences in visual field integrity when subjects were required to divide their attention between two tasks.
- Losses in attentional visual field-integrity, total UFOV, and UFOV-DA tended to accelerate between ages 50 and 70.
- Deterioration in PRT, Pelli-Robson low-contrast acuity, and distant visual acuity generally accelerated after age 70.

<u>Study question 4</u>: Is VTP by itself predictive of crashes for certain age groups?

- None of the tests yielded scores that were predictive of crashes for subjects in the 40-51 or 52-69 age groups.
- Scores on the department's Snellen acuity test and the standard visual field test were significantly associated with crashes in the 26-39 age group. These test scores accounted for 0.9% and 1.8% of the total variation in crash involvement, respectively.
- Performances on the standard visual field and the Visual Attention Analyzer were significantly correlated with crashes in the 70+ age group. The percentage of total variance in crash involvement accounted for by these test scores ranged from 1.4% to 2.9%.

<u>Study question 5</u>: Is VTP predictive of crashes for <u>all age groups</u> combined after statistically adjusting for differences in crash involvement due to differences in gender, age, and amount of exposure?

- Performance on the Synemed Perimeter standard and attentional visual fields tests and the Visual Attention Analyzer UFOV test were significantly correlated with crashes after adjusting for differences in gender, age, and reported hours-per-week and miles-per-week of driving. The proportion of total variance in crash involvement explained by VTP ranged from 0.9% to 1.9%.

Study Question 6: Is VTP more predictive of crashes for certain age groups after statistically adjusting within each age group for gender, age, and amount of exposure?

- Visual Attention Analyzer scores for total UFOV, PRT, and UFOV loss associated with divided attention were significantly associated with crashes after adjusting for gender, age, and driving exposure for drivers in the 70+ age group. The percentage of crash variance that was accounted for ranged from 4.1% to 4.3%.
- Scores on the other tests evidenced no significant predictive value for 70+ year old subjects after adjusting for gender, age, and exposure.
- None of the test scores were significantly associated with crash involvement for drivers in the younger age groups after adjusting for gender, age, and exposure.

Study question 7: To what extent do poor-vision drivers and older drivers self-restrict? How does the magnitude of self-restriction vary with VTP and age?

- Reported level of self-restriction was highly variable both with respect to visual ability loss and age.
- None of the vision test scores, nor driver age, accounted for more than 7% of the variation in any of the reported types of self-restriction: night-driving frequency, avoidance of rain or fog, avoidance of sunrise or sunset, avoidance of driving alone, avoidance of left turns, and avoidance of heavy traffic.
- In general, loss in visual ability was associated with reduced night driving and avoidance of rain or fog, sunrise or sunset, driving alone, and left turns.
- Only the Visual Attention Analyzer scores were associated with avoidance of heavy traffic.
- Avoidance of sunrise or sunset was especially associated with scores on the Pelli-Robson low-contrast acuity test, the attentional visual field test, and the UFOV test.
- The vision test scores most strongly associated with self-restriction were total UFOV loss and UFOV loss associated with divided attention.
- Older drivers tended to self-restrict more than did younger drivers, primarily by avoiding driving at night, sunrise, and sunset.

Study question 8: Is the relationship between VTP and crashes moderated (mediated) by self-restriction?

- Different forms of self-restriction significantly moderated (mediated) the relationship between crashes and performance on the DMV Snellen test, the Pelli-Robson low-contrast acuity test, the Smith-Kettlewell Low Luminance Card, the Synemed Perimeter standard and attentional visual fields tests, and the Visual Attention Analyzer. The percentage of crash variance predicted within age group by VTP moderated by self-restriction after adjusting for gender, age, and exposure ranged from 1.1% to 11.4%. Significant moderation by self-restriction indicates that the strength of the association of poor VTP with crashes was significantly different for low versus high levels of self-restriction.
- In some instances, the relationship between VTP and crashes was moderated by age and level of self-restriction. One of the most dramatic examples of this is the

variation in predictive value of Pelli-Robson low-contrast acuity among drivers aged 26-39. Drivers in this age group who have poor contrast sensitivity and who never avoid driving in heavy traffic are predicted to have an elevated crash rate relative to drivers with good contrast sensitivity. However, the reverse (very low crash risk) is predicted for drivers who have poor contrast sensitivity and who often avoid driving in heavy traffic.

- The results for the 70+ year old age group suggest that older drivers' self-restriction tends to be less than wholly adequate compensation for worsening impairments of multiple visual abilities critical to safe driving.

Study question 9: Is there any evidence of other variables moderating (mediating) the relationship between VTP and crashes?

- The relationship between VTP and crash frequency was significantly moderated by performance on the DMV Snellen test for all the experimental vision tests except the Smith-Kettlewell low-luminance high-contrast near-acuity chart, the Synemed perimeter standard and attentional visual field tests, and the Vision Attention Analyzer UFOV-DA.
- The moderating effect of DMV Snellen test performance was such that poor VTP was more strongly associated with crashes for subjects who failed the DMV Snellen test than for those who passed it. For example, for Snellen passes the number of crashes predicted by PRT was about the same for drivers having poor PRT and those having good PRT. However, for Snellen fails the number of crashes predicted for subjects having poor PRT was much higher than that for subjects having good PRT.
- VTP predictive value after adjusting for gender, age, and exposure was greatly increased when the prediction was limited to Snellen fails. For example, the percentage of total variance in crash involvement explained by the Smith-Kettlewell low-luminance low-contrast near-acuity scores was nonsignificant (zero) for all subjects combined, but 16.3% for Snellen fails. The percentage of variance in crashes for Snellen fails that was accounted for by vision test scores ranged from 8.0% to 16.3%.
- VTP predictive value when limiting prediction to Snellen fails was further enhanced by incorporating the moderating effects of self-restriction. For example, the predictive values of Pelli-Robson low-contrast acuity, total UFOV, and PRT were 2 to 3 times higher for Snellen fails than they were for subjects in general. The percentage of crash variance predicted by VTP in this model ranged from 8.5% to 26.2%.

Study question 10: What are the operational and policy implications of the results?

The benefits and costs of implementing one or more of the experimental vision tests would depend upon the test's predictive validity, equipment and staff time requirements, including that needed for any follow-up assessment, the effectiveness of countermeasures, and the number of individuals to be tested. The following considerations should be noted:

- From the standpoint of crash predictive validity, the Pelli-Robson low-contrast acuity test, and PRT assessment as measured by the Visual Attention Analyzer, offer immediate promise for improving the identification and regulation of drivers having impaired visual abilities critical to safe driving.
- The Pelli-Robson low-contrast acuity chart is commercially available, quick (about 1.5 minutes), easy to administer, and relatively inexpensive ($300 per chart).
- PRT can be measured using a much simpler and less costly testing apparatus than the Vision Attention Analyzer and would take only 4-5 minutes. Several microcomputer-based perceptual reaction time tests are now commercially available.
- Any new vision test would be most effective in minimizing crashes and maximizing mobility if it were implemented in the context of a structured remedial/graded licensing program that included:
  (a) feedback about vision test performance,
  (b) counseling about remediation and/or compensation,
  (c) appropriate license conditions and guidelines for their application, and
  (d) guidelines for suspending, revoking, or not licensing unsafe drivers.
- Costs could be reduced if implementation were on a selective basis, for example, giving one or more of the new tests to only older drivers or only Snellen fails. Although reducing the size of the target group would also decrease the potential number of crashes that might be prevented, it is clear that the new vision tests have much greater validity in identifying crash involved drivers among the subjects over 70 years old and/or who failed the Snellen test.

To fully realize the VTP predictive values estimated from the models evaluated in this study, one would need to adjust each vision test score in accordance with the values and weights of the other variables (gender, age, exposure and passing or failing the DMV Snellen test) in the pertinent regression equation. Adjusting test scores in this manner would represent a departure from present departmental policy.

<u>Recommendations and Action Items</u>

- Consider referring all DMV Snellen test fails to a vision specialist through the DL 62 vision referral process. Full realization of the benefits of this recommendation would require (1) standardizing Snellen chart lighting, (2) revising the department's Driver License Manual so as to provide a clear statement of the Snellen test screening standard and protocol, (3) maintaining strict adherence to the department's screening standard and protocol, and (4) specifying a more comprehensive and rigorous vision examination than is presently done through the DL 62 process.
- Cross validate the most promising tests (Pelli-Robson low-contrast acuity and PRT assessment) in a large-scale demonstration project.
- Continue research on developing improved assessment tests and protocols for drivers with age-related impairments. The results of this effort, combined with the large-scale field study recommended above, will provide the basis necessary for developing a remedial/graded licensing program for drivers with age-related functional impairments.

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INTRODUCTION

Study Objective and Rationale

This study assessed the utility of five experimental vision tests. Two of these tests measure components of visual attention, and the other three measure abilities necessary for seeing objects and borders under low-contrast and/or low-light conditions.

Enhanced vision testing is necessary to more effectively identify and regulate drivers having impaired visual abilities critical to safe driving. The department's current vision screening procedures assess visual acuity; it is determined whether driver license applicants can see a minimum level of detail. However, seeing detail is only one of the visual abilities important for safe driving. Most of the visual abilities likely to be important for safe driving, such as seeing objects under low-contrast conditions or in dim light, are not typically tested by licensing agencies or by the vision clinician.

Additional vision tests may be useful for addressing a variety of objectives, such as: (1) identifying drivers with vision problems, (2) demonstrating to the driver substantial vision impairments, (3) counseling the driver about remediation and/or compensation, (4) diagnosing vision problems in drivers who have poor driving records, (5) alerting the examiner to what to look for and be careful of on a road test, (6) suspending, revoking, or not licensing drivers who cannot adequately compensate for impaired visual abilities critical to safe driving, and (7) aiding the identification of appropriate license restrictions that could be either recommended or imposed by the licensing agency.

Visual acuity, other sensory abilities, and visual perceptual abilities are known to decline with age, along with numerous other human abilities. In completing the literature review phase of a NHTSA-funded project to develop an assessment system for identifying and evaluating the driving competency of older drivers with dementia or age-related frailty, Janke (1994) reached the following conclusion:

> ... some studies have concerned themselves with crash rates adjusted for exposure while others have not. The former address the question of driving competencies–many of which can be assumed to be impaired in elderly drivers with medical conditions–and the risk of driving to the individual driver when he or she is on the road. The latter deal with the question of the societal risk posed by an impairment group, which may be negligible because of the group's voluntary or involuntary driving limitations. If impaired drivers control their crash risk through self-limitations of their driving, <u>and succeed in this</u> (however success may be defined), they do not constitute a societal problem and the role of the licensing agency vis-à-vis their impairment should arguably be only an advisory one.

Empirical inquiries into compensation (for example, avoiding rush hour traffic, not driving at night, and always wearing corrective lenses) for age-related declines in vision functioning have not been unanimous in their findings (Schieber, 1994; Shinar &

Schieber, 1991). Older drivers have been reported to be cognizant of their vision-related driving disabilities and to compensate accordingly (Kline, Kline, Fozard, Kosnik, Schieber, & Sekuler, 1992). They have also been reported to be unaware of poor vision, and consequently fail to compensate (Johnson & Keltner, 1983; Shinar, 1977).

Although it is possible that the results of the present study may be deemed sufficiently definitive to warrant statewide implementation of one or more of the experimental tests, a more realistic objective is the isolation of those vision tests showing the most promise for further validation in a large-scale statewide study.

<u>Role In Department's Overall Competency Enhancement Effort</u>

This study addresses one component of a comprehensive departmental plan to enhance the competency level of the California driving population (McKnight & Stewart, 1990; California DMV, 1990). It is important that the present paper be viewed in this context. The components of the total plan, not all of which have been initiated as of this date, are described below.

- Development of a more stringent, competency-based knowledge test.

- Development and evaluation of an enhanced vision test system, involving measures of glare sensitivity, night vision, and useful field of view.

- Development and evaluation of a battery of perceptual and cognitive tests aimed at detecting functional, as distinct from chronological, aging. The battery would be correlated with drive test scores and accident frequency to determine if it could be used as a pre-road test screening device or self-assessment tool.

- Development and evaluation of a part-task simulator to measure competency domains not included on traditional road tests (hazard recognition, freeway merging, accident-avoidance skill, etc.).

- Development and evaluation of a strategy for customizing license restrictions to the needs and performance levels of applicant drivers.

- Development and evaluation of knowledge tests and informational materials that are relatively language-free (e.g., audio-visual tests, video manuals).

- Development and evaluation of a more reliable and more valid road test.

It is also important to understand how driver licensing functions to enhance competency. Although driver testing, including vision assessment, is often thought of as a method of selection, it is more appropriate to view testing from the perspective of quality assurance as advocated by McPherson and McKnight (1981) and Peck (in preparation). Under this paradigm, testing is intended to serve as a means for maintaining driving competency at a specified level, and to reduce deficiencies through appropriate remedial and license-control mechanisms. In the case of vision, the most obvious example is to require corrective lenses in order to meet a state's minimum visual acuity standard for full driving privileges.

It is essential for a proper interpretation of the policy implications of driver assessment research to understand the distinction between selection and quality assurance. From a quality-assurance perspective, screening standards, by design, alter the level and range of abilities critical to safe driving. This, in turn, attenuates any intrinsic correlation between, say, visual acuity and crash rates because the testing standard itself has already elevated and "homogenized" the visual acuity level of the licensed driving population. For these reasons, attempts to validate extant vision screening standards by correlating test scores with subsequent crash frequency of licensed drivers are not likely to prove informative or fruitful.

Department's Vision Screening Standard, Form DL 62, and Vision Guidelines

In-person driver license applicants are required to demonstrate a Snellen distant visual acuity of at least 20/40 with or without corrective lenses with both eyes together, and with each eye separately. All applicants are first administered the Snellen test which requires reading a line of 20/40 letters on a Snellen chart. Snellen fails are administered the Optec 1000 or the Ortho-Rater visual acuity test. The Optec 1000 and the Ortho-Rater are mechanical vision testers that require the applicant to identify the location of a checkerboard pattern in successively smaller targets numbered from 1 to 6, with 6 being the smallest. Applicants failing the vision screening are given a copy of form DL 62, Report of Vision Examination, to be completed by a vision specialist.

A completed form DL 62 provides the department with information about the applicant's visual acuity, visual field, and whether the applicant suffers a vision condition(s) and the prognosis for the vision condition(s). Guidance in interpreting and acting on information provided in the DL 62 is provided by the vision guidelines which are comprised primarily of a chart listing vision conditions, their definition, and actions to be taken.

The limitations of assessing visual acuity, visual field, and other traditional vision-assessment techniques, especially when applied to older drivers, is succinctly summarized by Schieber (1988):

> Traditional assessment techniques have proven to be invaluable for screening and optimizing visual performance under ideal conditions, such as reading high-contrast text or well-illuminated highway signs. However, the predictive validity of these traditional techniques often decreases when visibility conditions are compromised by low levels of illumination (e.g., the highway at night) or inclement weather (rain, fog, etc.). Consequently, individuals who demonstrate "normal" visual capabilities under standard clinical conditions can differ greatly under adverse viewing conditions (Committee on Vision, 1985).
>
> There is mounting evidence that this inability to generalize the results of traditional measures of vision to dynamic, nonstandard environments (i.e., the real world) may be exacerbated in the case of older adults. Age-related visual pathologies such as glaucoma, cataract, and retinal disorders (e.g., maculopathy) are often associated with normal scores on standard acuity tests. Yet many of these patients with normal acuity suffer from marked

deficits in their ability to function visually under nonstandard conditions such as low illumination, low contrast, and glare.

Experimental Vision Tests and Rationale

Table 1 lists and defines vision functions critical to safe driving (e.g., Decina & Staplin, 1993; Janke, 1994; Leibowitz, 1993; Owsley & Ball, 1993; Schieber, 1994; Shinar & Schieber, 1991). As the visual system ages, it normally undergoes a number of functional changes: visual acuity decreases, contrast sensitivity decreases, glare resistance decreases, the rate of dark adaptation slows, light sensitivity decreases, visual-field diameter decreases, reaction time to visual events slows down, and finally, dividing attention among multiple visual events becomes increasingly more challenging as does selectively attending to one visual event, that is, keeping from being distracted by other stimuli (Janke, 1994).

Table 2 identifies the vision functions measured by the vision tests evaluated in this study. A detailed description of these tests is presented in the Methods section.

Table 1

Vision Functions Critical to Safe Driving

Vision function	**Quick definition**	**Use in driving**
Sensory processes		
Visual acuity	Seeing detail.	Reading signs. Identifying objects: Is it a pot hole, oil slick, or just a black spot?
Contrast sensitivity	Seeing objects and borders.	Seeing objects lying in the roadway. Seeing the dark car parked in the shade. Seeing faded lane boundary markings.
Glare resistance	Seeing through glare. (Glare: veiling haze caused by having to face bright light such as headlights or setting sun. Glare reduces contrast.)	Seeing the cars and road ahead while facing a steady stream of headlights. Seeing the pedestrian crossing in front of you against the setting sun.
Dark adaptation and light sensitivity	Rapidity in adjusting to and seeing in dim light.	Seeing hazards in dim light, especially immediately after having driven down a brightly-lighted street.
Visual fields	Noticing objects and events left, right, above, and below one's focal point.	Noticing activity reflected in the rear-view mirror. Keeping centered in your lane. Noticing hazards on the far left and the far right.
Attentional processes		
Reaction time to visual events	Time required to see details or objects, still or moving.	Seeing hazards and reading signs in a timely manner.
Divided attention	Keeping track of two or more visual events.	Keeping track of two or more hazards at the same time.
Selective attention	Ignoring irrelevant stimuli.	Searching for signs or hazards.

Table 2

Vision Tests Evaluated in this Study

Vision test	Vision measured
Pelli-Robson Low-Contrast Acuity Test (P-R L-C A)	Low-Contrast Acuity Loss
Smith Kettlewell Low-Luminance (SKILL) Card - High-Contrast Near-Acuity Chart (SKILL-HC) Low-Contrast Near-Acuity Chart (SKILL-LC)	High-Contrast Near-Acuity Loss Low-Contrast Near-Acuity Loss
Berkeley Glare Tester (BGT) - Glare Off (BGT-Off) Glare On (BGT-On)	Low-Contrast Near-Acuity Loss Low-Contrast Near-Acuity Loss in the Presence of Glare
Modified Synemed Perimeter - Standard Visual Field (Stndrd/Field) Attentional Visual Field (Attn/Field)	Standard Field-Integrity Loss Attentional Field-Integrity Loss
Visual Attention Analyzer - Total Useful Field of View (UFOV) Perceptual Reaction Time (PRT) Divided Attention (UFOV-DA)	Total UFOV Loss Perceptual Reaction Time UFOV Loss Associated with Divided Attention

The Pelli-Robson low-contrast acuity test, SKILL Card test, Berkeley Glare Tester, and the Standard and Attentional Visual Field tests are the vision tests recommended by the Smith-Kettlewell Eye Research Institute (SKERI). These five tests are either prototypes or modifications by SKERI of commercially available vision tests, and are referred to in this study as the Smith-Kettlewell (SK) vision tests. Steinman (1990) conducted a DMV-sponsored study of these five tests along with seven other vision tests. She found that scores on the five recommended tests were statistically significant predictors of membership in a group that had experienced at least three crashes in 3 years versus a no-crash group (all drivers 55 years or older).

The Visual Attention Analyzer UFOV test was included in this study because of a recently published study showing that older drivers (57 to 83 years of age) who failed the UFOV test had approximately 4 times more crashes in a previous 5-year period than those who passed the test (Owsley, Ball, Sloane, Roenker & Bruni, 1991). UFOV test performance explained 13% of the variance (differences) in at-fault crash rate among the 53 subjects recruited from the university ophthalmology clinic. These findings are generally regarded as remarkably good by the driver-screening research community.

UFOV is the area of the visual field in which useful information can be rapidly extracted (without eye or head movements) from a visual display of similar complexity to that encountered in everyday driving. Subjects actually take three tests whose scores are combined to yield a measure of the subjects' UFOV loss. The first test estimates UFOV loss associated with information processing speed. It is used to determine the shortest stimulus duration in which the subject can identify the centrally-presented target (a silhouette of a car or a truck) 75% of the time. In other words, the Visual Attention Analyzer is used first to estimate the subject's perceptual reaction time. In addition to a system-scaled estimate of UFOV loss associated with information processing speed, the system also stores the estimates of the subjects' actual perceptual reaction times. The other two tests measure UFOV loss associated with divided attention and selective attention.

The present study evaluated total UFOV loss, UFOV loss associated with divided attention (for comparison with performance on the Synemed Attentional Field test), and PRT. PRT is one of the primary abilities challenged by both UFOV tests and tests of dynamic visual acuity (DVA). DVA is the first visual ability to have been consistently related to crashes. Burg (1967) reported that performance on the DVA task accounted for approximately 3% of the variance (differences) in crash frequency in a previous 3-year period among 17,000+ California drivers ranging in age from 16 to 92 years. DVA is generally defined as seeing detail in a moving object. Seeing detail in a moving object challenges a number of abilities relevant to safe driving. Perceptual reaction time is one of those abilities. Even though Burg (1964) cites the apparent greater face validity of DVA versus static visual acuity as the rationale for evaluating its relationship to driver record, a more insightful rationale is tucked away in the discussion section of his preliminary report on the ongoing large scale study.

> It is possible that static acuity (SA) is but one determinant of DVA, while there may be other factors underlying DVA performance, such as, for example, oculomotor coordination, neck muscle coordination, perceptual reaction time and the like, that are also important to successful performance of the visual task in driving. In other words (to use Guilford's [1956] terminology), DVA may measure other factors which are "component variances" in the driving performance criterion, <u>in addition to</u> static acuity. If it is indeed the case that the DVA test has more elements in common with the visual requirements in driving than SA, then it is entirely logical to expect DVA score to predict driving record more adequately than SA scores. (pp. 94-95)

<u>Study Questions</u>

The study was designed to address a series of interrelated questions which in turn provide the structure of the report. The specific questions are listed below:

- How did the study subjects rate the six experimental vision tests? Do the different vision tests evidence face validity?
- Is vision test performance (VTP) by itself predictive of crashes for all age groups combined?
- How does performance on the department's Snellen test and the experimental vision tests vary with age?
- Is VTP by itself predictive of crashes for certain age groups?
- Is VTP predictive of crashes for <u>all age groups</u> combined after statistically adjusting for differences in crash involvement due to differences in gender, age, and amount of exposure?

- Is VTP more predictive of crashes for certain age groups after statistically adjusting within each age group for gender, age, and amount of exposure?

- To what extent do poor-vision drivers and older drivers self-restrict? How does the magnitude of self-restriction vary with VTP and age?

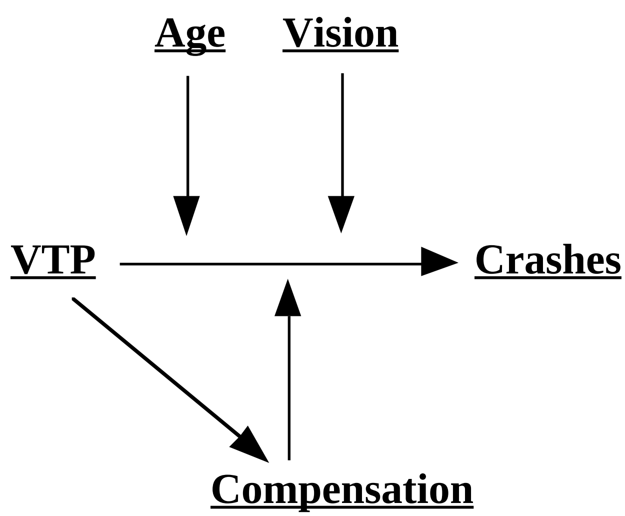
- Is the relationship between VTP and crashes moderated (mediated) by self-restriction?

- Is there any evidence of other variables moderating (mediating) the relationship between VTP and crashes?

- What are the operational and policy implications of the results?

A number of the above questions evolved from the author's hypothetical model of how vision and perception affect crash risk. This model is shown in Figure 1.

It is hypothesized that the nature of the relationship between VTP and crashes varies depending on the applicant's age, general visual ability (Vision), and levels of self-restriction (Compensation).



Note. The arrows pointing to the arrow between VTP and Crashes posit a moderating relationship.

Figure 1. Hypothetical causal model summarizing the posited relationships addressed in this study.

It is presumed that adequate compensation for impaired visual abilities is constrained by the following factors:

(1) the extent to which drivers cannot accurately perceive their visual abilities and/or cannot plan their driving accordingly (impaired cognitive abilities),
(2) the extent to which they attach relatively low importance to compensating for visual impairment(s),
(3) their purposes in driving, e.g., getting to work on time may keep drivers from avoiding driving in heavy traffic,
(4) the number and criticality of impaired visual and non-visual abilities,
(5) the magnitude of the impairments, and
(6) the availability of ways to compensate.

METHODS

Subjects

Subjects were Class C (non-commercial) license renewal applicants. Eligibility for participation in the study required that the Class C renewal applicant could not have renewed by mail and must have been a licensed driver in California for at least 12 years. These criteria were designed to help insure a representative sample of renewal applicants who were required to take the department's vision test. The minimum of 12 years of licensed driving in California was required because, under the renewal-by-mail program, a Class C driver license may be held for up to 12 years before the driver must renew in-person. Whether the renewal applicant had been a California driver for at least 12 years was determined primarily on the basis of when the applicant's driver license number was issued. In the case of the younger renewals, age was also considered because the same number issued to a child for an identification card is used later in issuing that person a driver license. Since junior permits can be issued to persons who are 14 years of age, renewal applicants had to be at least 26 years old to be included in the study. Eligible renewal applicants who were 26-27 years old were rare.

Participation in the study was represented as being mandatory. When the experimental vision tests were not being used or would be available shortly, the next eligible renewal applicant was approached for participation in the study. If the customer resisted taking the "new" tests and attempts at persuasion failed, the customer was processed as usual. The study goal was to test at least 350 subjects in each of four different age groups: 26-39, 40-51, 52-69, and 70+.

Apparatus

Of the vision tests evaluated in this study (Table 2), the Pelli-Robson low-contrast acuity test (Pelli, Robson, and Wilkins, 1988), the Smith-Kettlewell Low-Luminance Card (prototype), and the Berkeley Glare Tester (Bailey and Bullimore, 1991) all have the advantage of being letter charts like the department's familiar Snellen charts. The Pelli-Robson chart is read at a distance of 2 meters (a little more than 6 feet). The letters from left to right and from top to bottom progressively fade out as if they have to be read in thicker and thicker fog. Subjects who normally wear glasses for seeing detail at a distance versus close-up were instructed to wear their distance glasses or look through the top portion of their bifocals. The two SKILL Card charts and the BGT chart are viewed at a distance of 40 centimeters (about 16 inches). From the top to the bottom of these three charts, each line of letters is smaller than the line preceding it.

Subjects who normally wear reading glasses were instructed to wear them or look through the bottom portion of their bifocals. The subject was offered a pair of +2.50 diopter reading glasses if s/he usually wears reading glasses, but did not have reading glasses with them. One of the SKILL Card charts shows black letters on a white background (high-contrast letters). The letters on the other chart are black on a dark gray background (low-contrast letters on a low-luminance background). The letters on the BGT chart are gray on a white background (low-contrast letters). The BGT chart is mounted on a translucent screen behind which are light bulbs. The chart is read in the presence and in the absence of glare. The low-contrast SKILL Card chart is like the worn-darkened lane striping about a busy intersection, whereas the BGT-Off low-contrast chart is like a white car viewed in the fog.

The Pelli-Robson and SKILL Card charts require light levels commonly encountered in DMV field offices, however, care needs to be taken to insure there is enough light. The BGT test is designed to be administered in a dark or very dimly-lighted room. Each of these three tests requires no more than 3 minutes to administer.

A modified Synemed perimeter (Optifield II) was used to measure the portions of the visual fields thought to be most relevant to driving. A perimeter looks like half of a large globe about two-and-a-half feet in diameter. The subject is seated so that s/he is looking into the globe at a small spot of red light at the far end of the globe. In the Standard Visual Field test the subject was instructed to keep their eyes focused on the red fixation-light and to press and then release a button each time s/he saw a green light flash. Test spots (the green lights) were presented five times at eight different distances from the red focal light along each of five meridia (roughly like the spokes of a wheel). The meridia stretched to the upper right (where most rear-view mirrors are located), the far left and the far right, and the lower left and lower right (where lane boundaries would be seen in one's side vision). In the Attentional Visual Field test the red fixation-light irregularly blinked on and off. In addition to having to press the button each time a green light appeared, the subject was required to count and remember how many times the red fixation-light blinked.

The Standard and Attentional Visual Field tests must be given in a dimly-lighted room. Each of these two tests requires about 6 minutes to administer.

Enough normative data existed to develop referral criteria and a referral letter for poor performance on the Pelli-Robson chart, the SKILL Card, the Berkeley Glare Tester, and the Standard Field test. Subjects scoring worse than 99.5% of those in their age group were advised to be examined by a licensed eye-care practitioner if they had not already done so.

The Visual Attention Analyzer UFOV test (e.g. Ball, Owsley, & Beard, 1990) requires the subject to view a large computer-linked screen from a fixed distance that is prescribed by a chin rest attached to the front of the Attention Analyzer. The subject is allowed to view the screen with or without glasses, whichever is more comfortable. The subject is under no time pressure to respond. Subjects in this study were told that:

> In each of the tests we will be attempting to find the point at which you are unable to perform the test. Everyone has a point where the test

> becomes impossible for them. So don't be worried when you can't see something. Everyone has this experience. This is the point we are looking for.

As noted in the introduction, the first of the three UFOV tests is used to determine the shortest stimulus duration in which the subject can identify the centrally presented target (a silhouette of a car or a truck) 75% of the time. Stimulus duration ranged in value from 14 to 250 milliseconds. Subjects unable to identify the target 75% of the time when allowed the maximum stimulus duration (250 milliseconds) were assigned a value of 325 milliseconds.

In each of the other two UFOV tests, the subject is required to perform a central task and a peripheral task. The peripheral target appears unpredictably, but equally often, at any one of 24 different locations along one of eight meridia (like eight equally-spaced spokes of a wheel) and at one of three distances from the center of the screen. In the divided attention test, the target is presented in isolation. In the selective attention test, the target is embedded in 47 distractor stimuli. After the peripheral target is displayed, masking visual-noise is projected to erase any afterimages. This is followed by a display consisting of an eight-spoke radial pattern corresponding to the eight meridia. This display remains until the subject makes a radial localization judgment by indicating on which spoke they believed the peripheral target had been presented. The subject gets no feedback on their performance.

As with the BGT and visual field tests, the Visual Attention Analyzer requires a dimly-lighted room. Time required to administer this test depends on the consistency of the subject's performance across test trials, and consequently, normally ranges from about 15 to 20 minutes.

<u>Data Collection</u>

Data collection procedures were pilot tested in the South Sacramento field office from January 8, 1992 through January 31, 1992. From February 5, 1992 through October 29, 1992, data were collected in three field offices deemed together to provide a representative sample of the Class C renewal applicants in the Sacramento-San Francisco Bay Area Region: Carmichael, El Cerrito, and Roseville. Throughout the time of the study, all Class C renewal applicants were supposed to have been requested to complete a Driving Habits Survey (see Appendix A). (However, this did not always occur.) Subjects were tested on one of three vision test batteries: SK1 (Pelli-Robson low-contrast acuity test, SKILL Card test, Berkeley Glare Tester), SK2 (the Standard and Attentional Visual Field tests), and the UFOV. The three test batteries were individually rotated among the three test offices. Test results were recorded on a score sheet. Immediately after each vision test, the applicant was administered a brief Customer Reaction Survey (see Appendix B). The customer was then escorted from the testing room to where the department's Snellen test could be administered as it is usually done. Snellen test pass/fail results were recorded on the subject's score sheet.

At the conclusion of the collection of vision test data, and after allowing sufficient time for the subjects' driver records to be updated, subjects' driver records were extracted for the 3-year period immediately prior to their test date and merged with the vision and driving habits survey data.

Data Analysis

Sampling bias was evaluated first by comparing the driving habits survey responses and driver records of subjects to the corresponding data collected from (1) those who were not selected for testing, (2) those who refused to be tested, and (3) those who started, but did not complete testing. The predictive value of performance on the different vision tests was evaluated using correlational and multiple regression techniques. In this approach, VTP predictive value is the extent to which variation in crash involvement is associated with variation in VTP. Stated a bit less technically, VTP predictive value is the strength of the association of poor VTP with crashes.[1] VTP predictive value was assessed by estimating the percent of variance (differences) in crashes that could be explained by variation in VTP. A hierarchical analytic strategy was used to determine whether prediction of crash involvement was enhanced after differences among subjects in age, gender, driving mileage, and other variables were statistically "removed." The other independent variables used as covariates depended on the hypotheses under evaluation. Analyses were conducted for all age groups combined and, where evidence of differential relationships within age existed, some analyses were conducted within individual age groups.

RESULTS AND DISCUSSION

Subjects

Completed driving habits survey forms (*N* = 18,376) were collected from 59.7% of the 30,769 renewal applicants who were eligible for inclusion in the study. One of the three experimental vision test batteries was completed by 20.0% (*N* = 3,669) of the eligible renewals who completed a survey form, which is a 11.9% sample of all the renewals who were eligible for inclusion in the study.

Table 3 shows the number of individuals in each of the four age groups who completed testing on one of the three test batteries. From hereon, "subject(s)" refers to an individual(s) that has completed testing on one of the three test batteries. Eligible drivers 52-69 years old are relatively uncommon and it would have required 2 to 3 more months of data collection to have raised their numbers substantially closer to the goal of 350 subjects tested on each of the three test batteries.

[1]Estimating the strength of the association of poor VTP with crashes which occurred in the 3-year interval prior to the measurement of the subjects' visual ability is a retrospective evaluation of VTP predictive value. One might argue, then, that it would be more correct to refer to VTP "postdictive" value rather than "predictive" value. For various reasons, especially practicality, estimates of postdictive value are commonly used, as is done here, as measures of predictive value. Furthermore, directly estimating VTP predictive value, that is, measuring the association of VTP with the crashes which occurred after vision testing, introduces a highly problematic form of measurement artifact. Undergoing special vision testing likely heightens subject drivers' awareness of their visual ability. Drivers having relatively poor visual ability may then compensate more than they would have if they had not undergone special vision testing (e.g., keep from driving after dark altogether), which in turn would reduce estimates of the strength of the association of poor VTP with crashes.

Table 3

Number of Subjects and Percentage by Vision Test Battery and Age Group

Age group	Vision test battery SK1	SK2	UFOV	Total
26-39	355 27.9%	309 26.6%	356 28.8%	1,020 27.8%
40-51	318 25.0%	303 26.1%	335 27.1%	956 26.1%
52-69	259 20.4%	233 20.1%	259 21.0%	751 20.0%
70+	340 26.7%	317 27.3%	285 23.1%	942 25.7%
Total	1,272	1,162	1,235	3,669

Table 4 shows the number of men and women subjects for each of the three test batteries.

Table 4

Number of Men and Women Subjects and Percentage by Vision Test Battery

Gender	Vision test battery SK1	SK2	UFOV	Total
Men	666 52.4%	627 54.0%	656 53.1%	1,949 53.1%
Women	606 47.6%	535 46.0%	579 46.9%	1,720 46.9%
Total	1,272	1,162	1,235	3,669

As would be expected if the tested renewals were randomly sampled, both the age and gender distributions are virtually the same for each test battery. Additionally, the proportions of men and women are consistent with large sample estimates for the California general driving population (53.9% men and 46.1% women). Although the response rates (percentage of eligibles surveyed or tested) are respectable, the rates are far from 100%, creating some potential for bias and constraints on generality. A key concern here is whether or not the participants and nonparticipants differed significantly on prior driving records. Participants did not differ from nonparticipants with respect to the most important variable: prior 3-year crash frequency. Significant differences were evident on prior conviction frequency. Tested subjects (*N* = 3,669) had fewer convictions than did eligible renewals not selected for testing (*N* = 14,168, a mean of 0.594 vs. 0.670, $p<.0001$) and renewals that refused to test (*N* = 539, a mean of 0.594 vs. 0.825, $p<.0001$). Renewals that refused to test were also slightly younger (a mean of 50.4 vs. 52.8, $p<.0008$) and reported driving fewer miles (a mean of 114.7 vs. 139.2, $p<.0003$). Renewals that did not complete testing (*N* = 29) were substantially older (a mean of 67.4 vs. 52.7, $p<.0001$), reported driving fewer hours per week (a mean of 4.76 vs. 8.00, $p<.0001$), fewer miles (a mean of 61.8 vs. 139.2, $p<.0001$), and driving less at night (a mean of 1.86 vs. 2.30, $p<.0009$, see Appendix A, question 9 for rating scale). Given the direction of the differences and their effect in reducing between subject variance, the probable effect of any bias would be to understate the correlation between VTP and crashes.

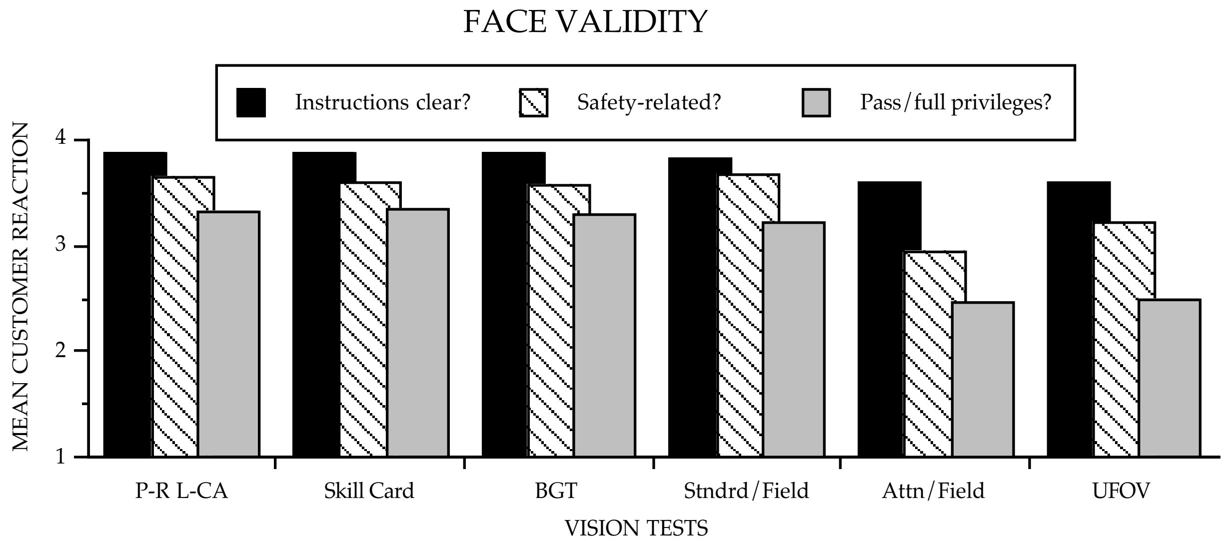
Crashes

Crashes were fairly evenly distributed between the three test batteries. About 15% of the subjects in each of the first three age groups had been crash-involved, whereas slightly less than 10% of the drivers in the oldest age group had been crash-involved during the 3-year period prior to testing. None of the subjects were involved in a fatal crash in the 3 years previous to their vision test date. Only 39 of the 512 total crashes occurred at night, which are too few to permit a meaningful analysis of night-crash correlates.

Study Question 1:
How did the study subjects rate the experimental vision tests? Do the different vision tests evidence face validity?

Figure 2 shows the subjects' mean rating of each experimental vision test. (See Appendix B for a description of the customer reaction survey). Tests challenging sensory abilities (Pelli-Robson low-contrast acuity test, Smith-Kettlewell Low-Luminance Card, Berkeley Glare Tester and Standard Visual Field test) evidenced face validity. Subjects on average rated these tests highly on: the clarity of instructions, the safety-relatedness of the tested sensory abilities, and the fairness of requiring driver license applicants to pass similar sensory tests in order to get full driving privileges.

Subjects on the whole were less certain about the fairness of the tests that challenged attentional processes (Attentional Visual Field test, Visual Attention Analyzer UFOV test). The clarity of the instructions were rated about the same as for the sensory tests, however, the safety-relatedness of the tested attentional abilities and the fairness of requiring the passing of similar attentional tests to get full driving privileges were not rated as highly as they were for the sensory tests. Attentional tests demand more effort from the subject than do sensory tests. Some customers reported enjoying the challenge, whereas others called it frustrating. Future customers taking a new attentional test would be more likely to complain than those taking a new sensory test. However, this would not be problematic per se because a complaint may be diagnostic of poor attentional abilities. Regression analyses showed that customers performing more poorly on one of the attentional tests tended to rate the test more negatively.



Note. Rating scale: 1-Definitely No, 2-Probably No, 3-Probably Yes, 4-Definitely Yes.

Figure 2. Mean customer reaction to the different vision tests.

Study Question 2:
Is VTP by itself predictive of crashes for all age groups combined?
For all age groups combined, none of the test scores were significantly associated with total prior 3-year crash involvement when considered in isolation–i.e., not adjusted for the effects of other variables. See Appendix C for a VTP intercorrelation matrix for each of the three test batteries.

Study Question 3:
How does performance on the department's Snellen test and the experimental vision tests vary with age?
Subjects' performance on the vision tests, which is summarized in Figures 3-9, is generally consistent with the following generalizations made by Shinar and Schieber (1991) based on the data collected by Shinar (1977):

1. All visual functions deteriorate with increasing age.
2. The amount, rate, and onset age of deterioration vary widely among the visual functions.
3. Deterioration in static acuity. . . is not significant before the age of 60, whereas, deterioration in the more complex tasks (such as DVA [dynamic visual acuity]) begins earlier and accelerates faster with increasing age.
4. The age-related average deterioration is accompanied by a marked increase in individual differences.

Specifically, deterioration in the three visual attention measures (Figures 7, bottom, and Figure 8) appears to accelerate between age 50 and age 70. Deterioration in perceptual reaction time (Figure 9) appears to accelerate after age 70 as does deterioration in Pelli-Robson low-contrast acuity (Figure 4) and the distant visual acuity needed to pass the department's Snellen test (Figure 3).

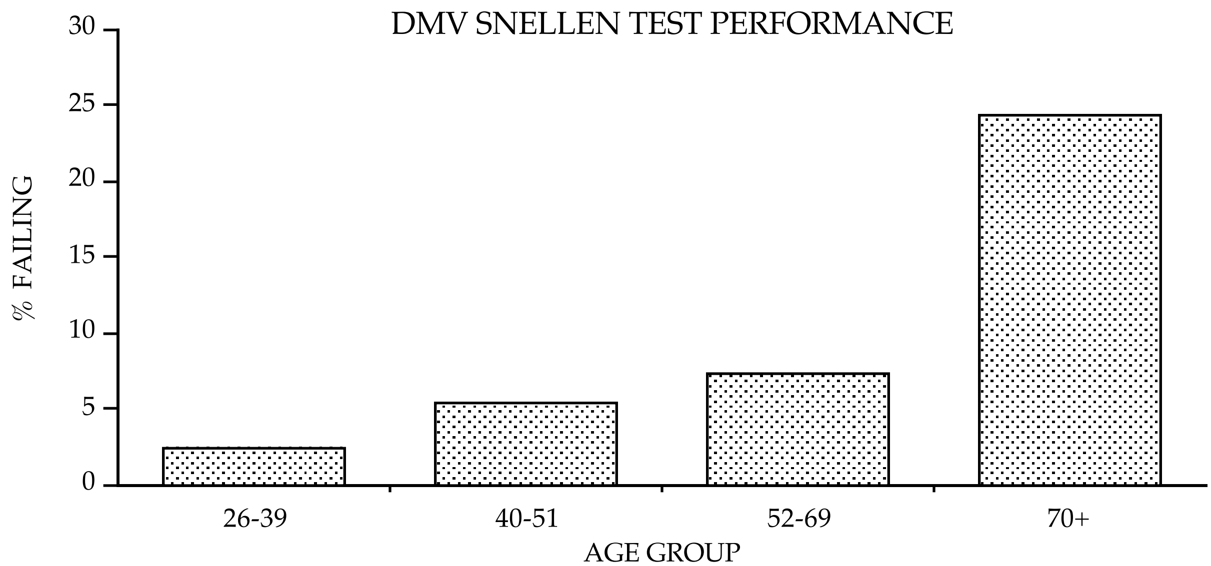
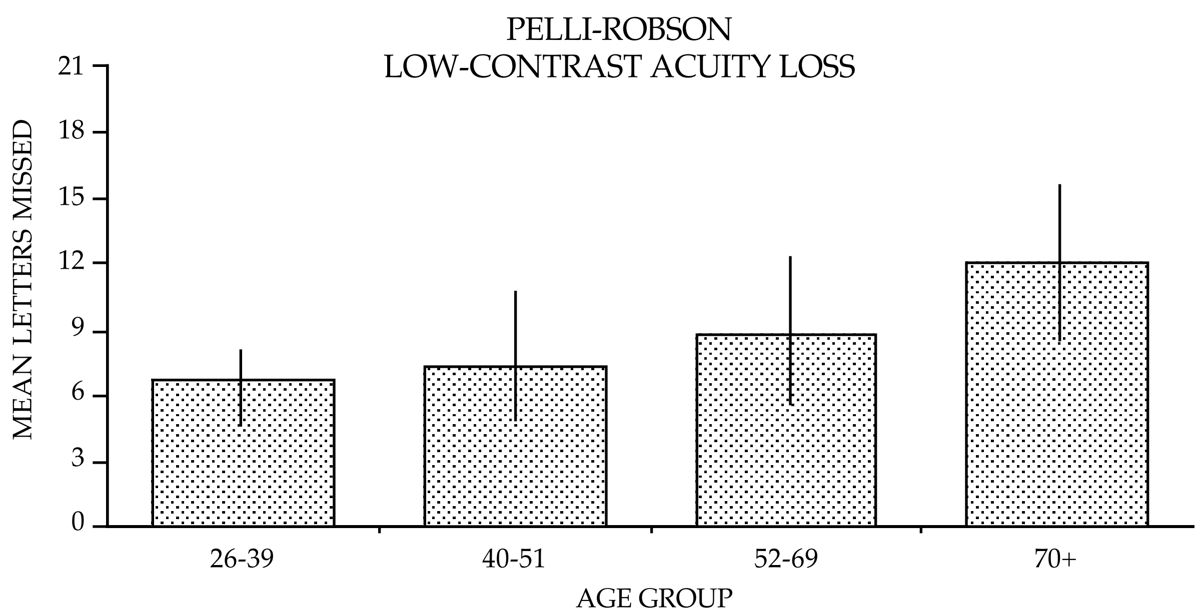


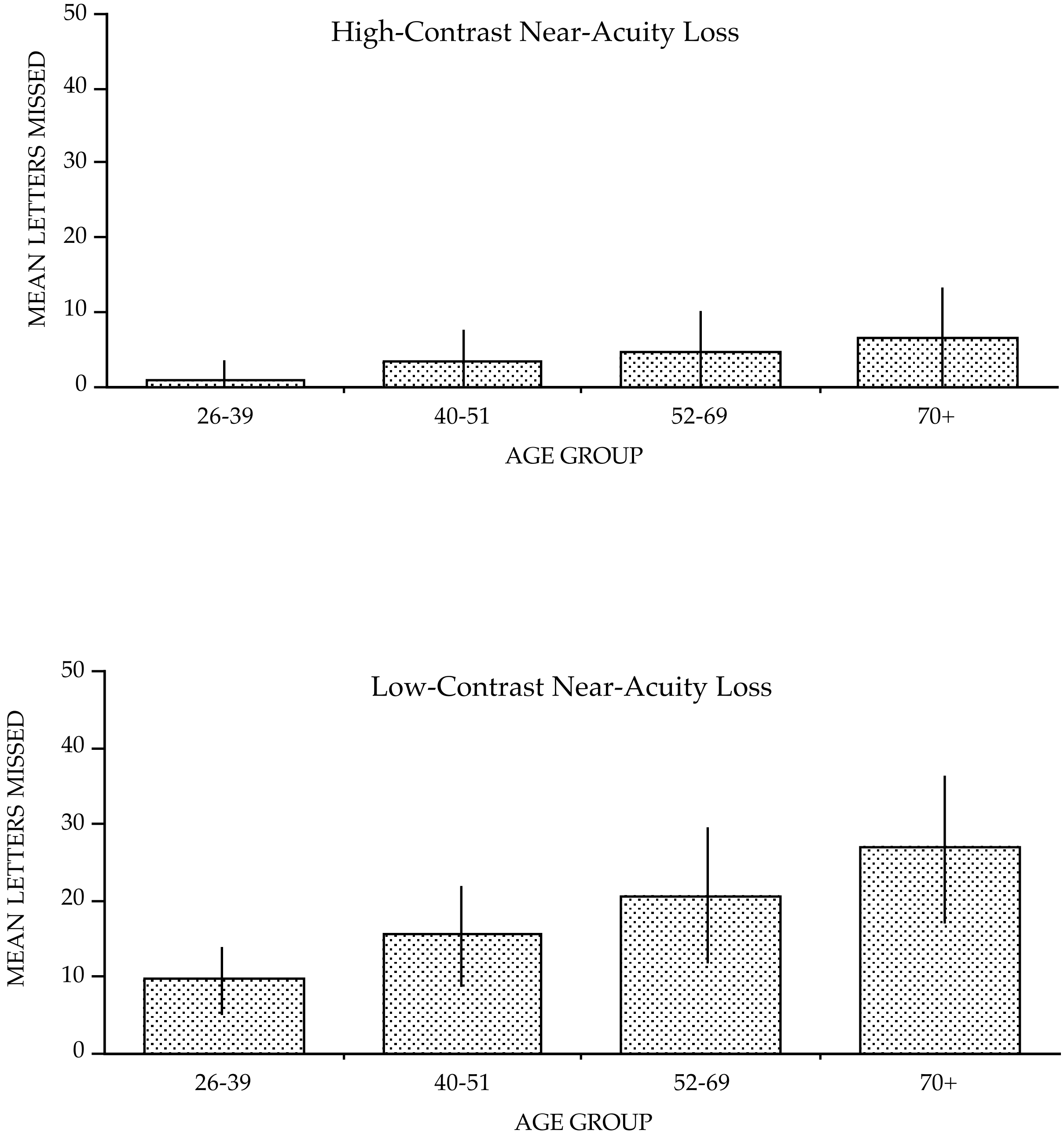
Figure 3. Percentage of subjects failing the DMV Snellen test by age group.



Note. Vertical lines represent plus and minus 1 standard deviation from the mean. About two-thirds of normally-distributed data fall in this interval. N = 48 total letters.

Figure 4. Mean number of letters missed on the Pelli-Robson low-contrast acuity chart by age group.

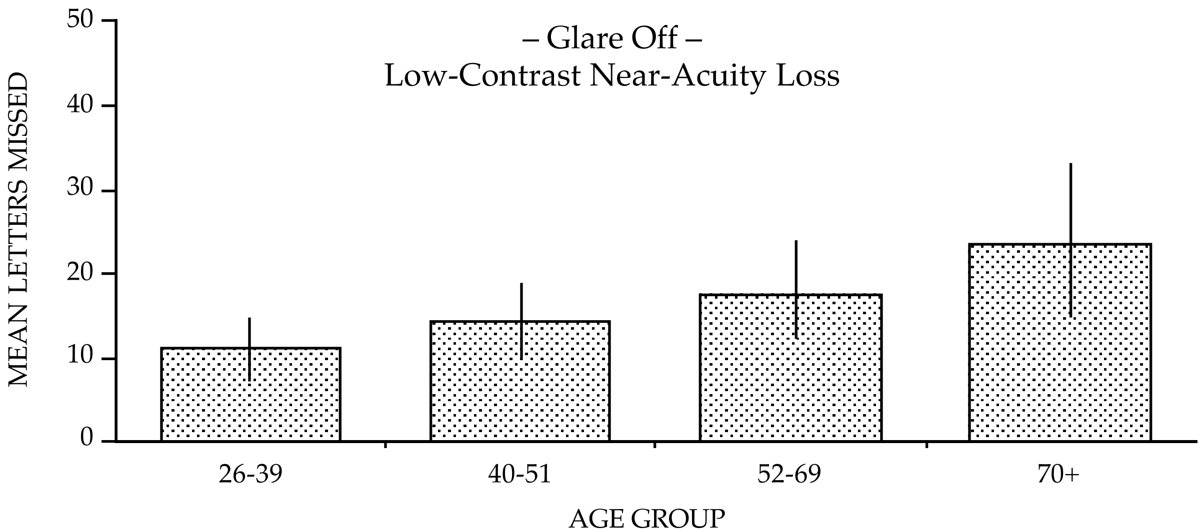
SMITH-KETTLEWELL
LOW-LUMINANCE CARD

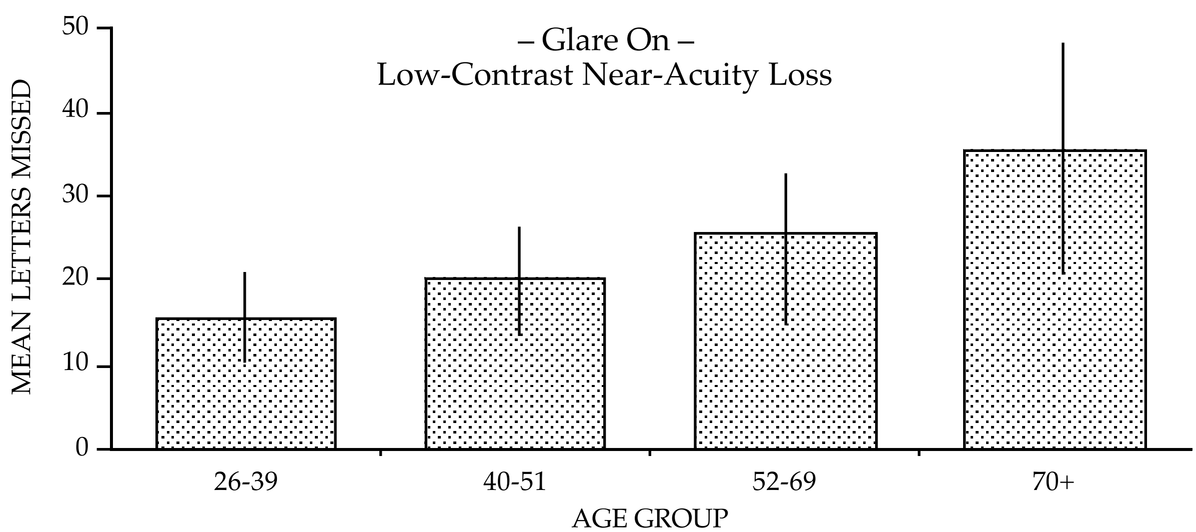


Note. Vertical lines represent plus and minus 1 standard deviation from the mean. About two-thirds of normally-distributed data fall in this interval. *N* = 100 total letters on each chart.

Figure 5. Mean number of letters missed on the two SKILL Card charts by age group.

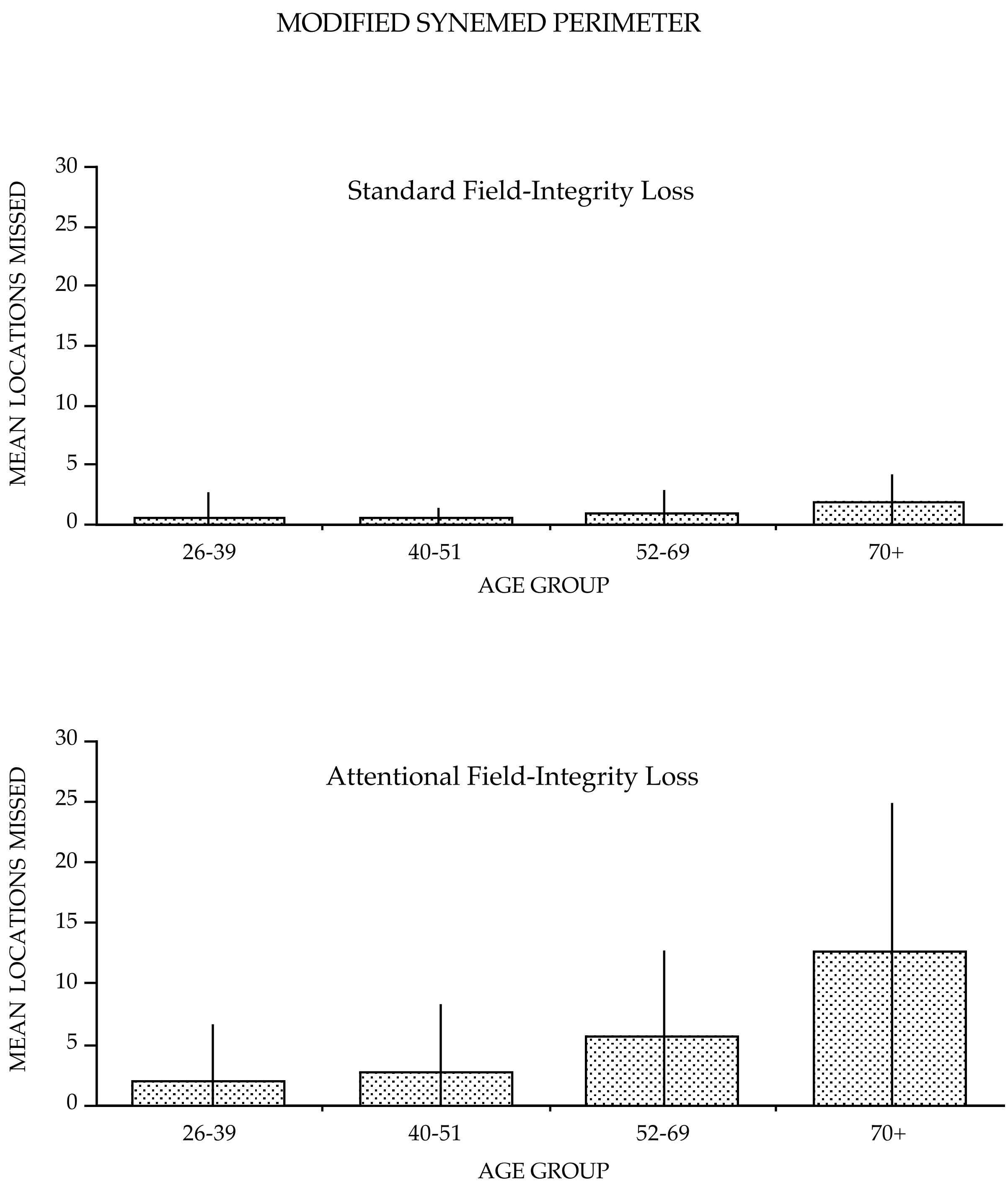
BERKELEY GLARE TESTER





Note. Vertical lines represent plus and minus 1 standard deviation from the mean. About two-thirds of normally-distributed data fall in this interval. *N* = 95 total letters on each chart.

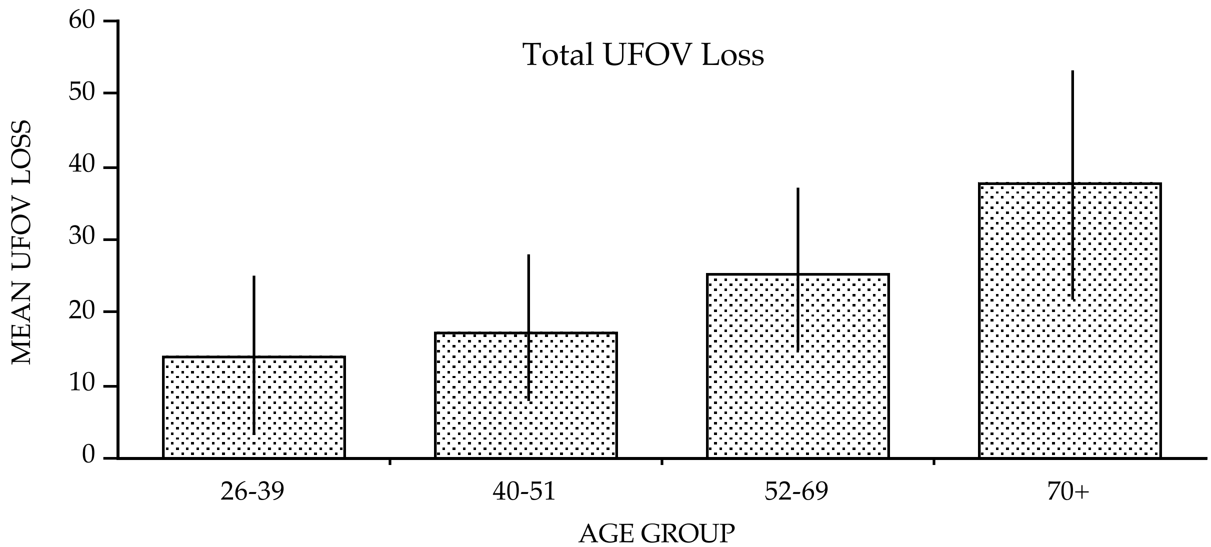
Figure 6. Mean number of letters missed on the two Berkeley Glare Tester charts by age group.



Note. Vertical lines represent plus and minus 1 standard deviation from the mean. About two-thirds of normally-distributed data fall in this interval. N = 39 total locations tested.

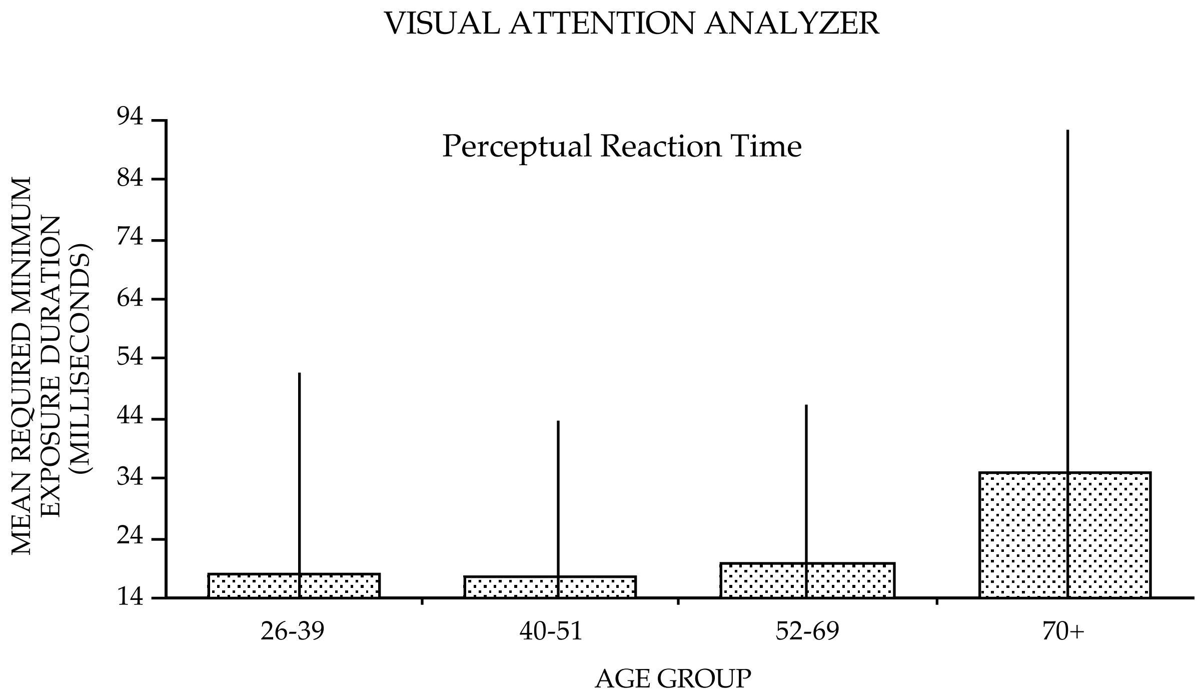
Figure 7. Mean number of locations missed on the two modified Synemed perimeter tests by age group.

VISUAL ATTENTION ANALYZER



Note. Vertical lines represent plus and minus 1 standard deviation from the mean. About two-thirds of normally-distributed data fall in this interval. UFOV maximum loss score = 90; UFOV-DA maximum loss score = 30.

Figure 8. Mean total Visual Attention Analyzer UFOV loss and mean UFOV loss associated with divided attention by age group.



Note. Vertical lines represent plus and minus 1 standard deviation from the mean. About two-thirds of normally-distributed data fall in this interval. Exposure duration ranged from 14 to 325 milliseconds.

Figure 9. Mean Visual Attention Analyzer estimates of perceptual reaction time by age group.

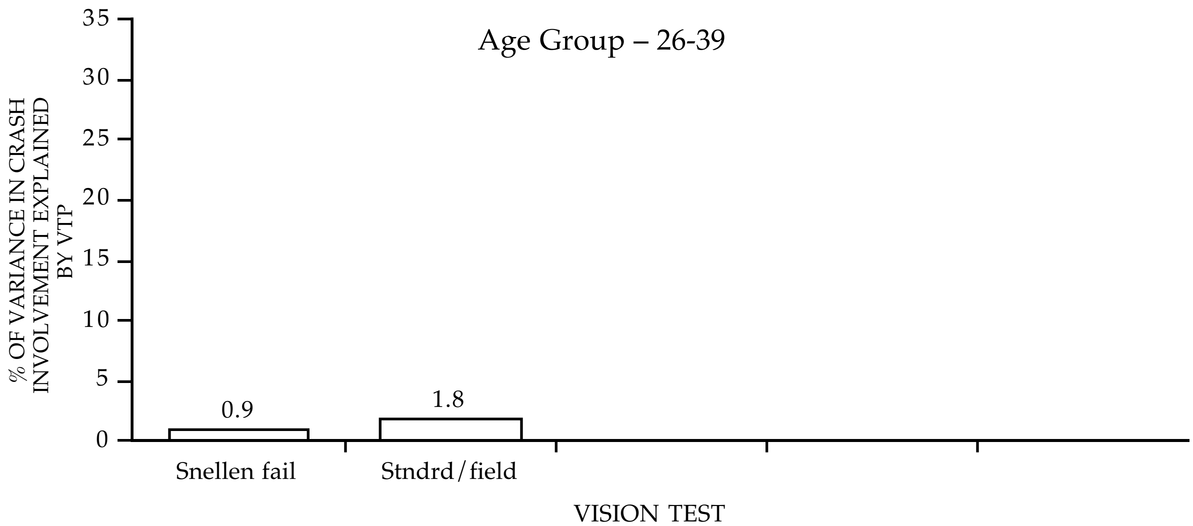
The results summarized in Figures 5-7 are consistent with the point made earlier about the vision clinician's standard vision tests (near and distant acuity, standard visual fields) being relatively insensitive to normal age-related changes in real-world visual performance. The top graph in Figure 5 shows how the best-corrected near acuity of 70+ year old drivers differs on average by only about three letters from that of 40-51 year old drivers when tested under optimal conditions (well-illuminated high-contrast text). However, when contrast and luminance are reduced (Figure 5, bottom), or when contrast is reduced by making the black letters gray and adding glare (Figure 6, bottom), 70+ year old drivers read 2-3 lines (5 letters per line) less than 40-51 year old drivers, a marked reduction in seeing detail. Figure 7 shows similar results for field integrity. Modified Optifield II standard field-integrity was on average excellent for all age groups (Figure 7, top). However, when an additional task was added to the test, requiring subjects to divide their attention between two tasks, 70+ year old drivers on average showed a marked deterioration in field integrity (Figure 7, bottom). They also showed very high variability in attentional field-integrity loss (see variation indicated by the vertical line for 70+ year old drivers in Figure 7, bottom). This means that some of the older drivers have very good visual divided-attention ability as measured with the modified Optifield II attentional field test. A similar result was found for visual divided-attention ability when measured with the Visual Attention Analyzer (Figure 8, bottom) and perceptual reaction time (Figure 9, bottom). However, there was only a very small percentage, if any, 70+ year old drivers with very good total UFOV (Figure 8, top) or very good low-contrast acuity (Figure 4, Figure 5, bottom, and Figure 6)

From the standpoint of individual variation in test scores, the Visual Attention Analyzer and the Synemed attentional test, especially for drivers aged 70+, offer the most potential as devices for screening out drivers presenting inflated crash risks due to sensory and attentional visual deficits.

Study Question 4:
Is VTP by itself predictive of crashes for certain age groups?

The results summarized in Figure 10 are estimates of VTP predictive values for the youngest and oldest age groups. (On none of the tests was VTP predictive of crashes for drivers in the 40-51 or 52-69 age groups.) In this and the remaining figures showing estimates of VTP predictive values, estimates are depicted only for the vision tests in which VTP was found to be a statistically significant ($p<.05$) correlate of crashes. As noted in the Methods section, VTP predictive value is the strength of the association of poor VTP with crashes. The predictive value of VTP was assessed by estimating the percent of variance (differences) in crashes that could be explained by variation in VTP. The graphs in the figures showing VTP predictive values are all scaled the same in order to allow the reader to easily compare the results summarized in the different figures. It is important to note that in this section none of the relationships are adjusted for covariation with other variables.

VTP PREDICTIVE VALUES



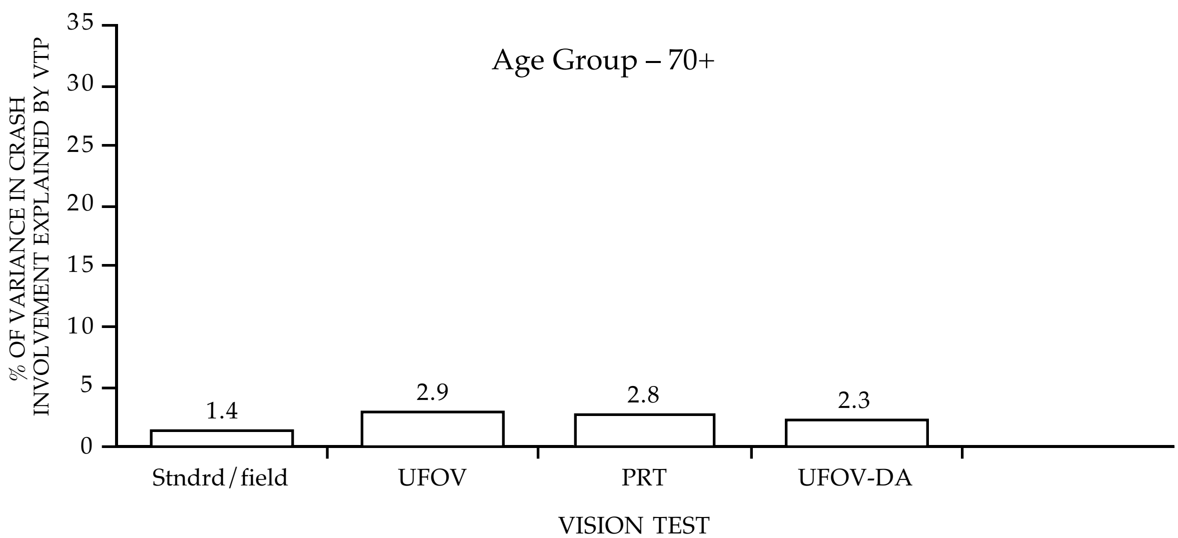


Figure 10. Percentage of variance in crash involvement explained by vision test performance (VTP) predictive values for the youngest and oldest age groups.

Figure 10 suggests that poor performance on the department's Snellen test is slightly related to increased crash frequency among drivers 26-39 years old, but not for drivers 40+ years old. Performance on the standard field test showed small, but statistically significant predictive value for the 26-39 and 70+ year old age groups. Significant results for the standard field test are surprising in that there was relatively little loss and little variation in standard field integrity as measured by the Synemed modified Optifield II (see Figure 7).

Figure 10 also shows that test scores obtained from the Visual Attention Analyzer had significant predictive value for drivers over 70 years of age. This result is consistent with the predictive potential noted earlier in connection with the large variability among drivers (70+) in Visual Attention Analyzer test scores. Even though the magnitude of the UFOV VTP predictive value is small (2.9%), it is substantially better than that recently reported by the Hartford Insurance Company/American Association of Retired Persons study (Brown, Greaney, Mitchel & Lee, 1993). The Hartford study (*N* = 1, 475) found virtually no relationship between UFOV loss and at-fault crashes in the 3-year period prior to testing for drivers 50+ years old (predictive value = 0.3%).

<u>Study Question 5</u>:
<u>Is VTP predictive of crashes for all age groups combined after statistically adjusting for differences in crash involvement due to differences in gender, age, and amount of exposure</u>?

Gender, age, and amount of exposure are known to be predictive of crashes (e.g., Gebers & Peck, 1994). Interest here is in whether, and to what extent, VTP is predictive of crashes after statistically "removing" differences among subjects in gender, age, and amount of exposure. Exposure was measured in this study as subject's reported hours per week and miles per week spent driving (see Appendix A, questions 2 and 3).[2]

Figure 11 indicates that performance on three of the vision tests (the modified Synemed perimeter standard and attentional visual field tests and the Visual Attention Analyzer UFOV test) significantly predicted crashes after adjusting for differences in gender, age, and amount of exposure.[3] Since on none of the vision tests was VTP by itself predictive of crashes for all age groups combined, these results indicate that the underlying relationships between VTP and crashes are obscured by differences in other variables (such as gender, age, and exposure) associated with both VTP and crashes.

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[2]Based on analyses of all the completed Driving Habits Survey forms (*N* = 18,376), it was found that the mean number of crashes increased generally linearly with increases in both of the exposure measures. Neither square root nor logarithmic transformation of the exposure data appreciably increased their correlation with crash involvement for all ages combined, renewals 60 years old or older (*N* = 6,050), or renewals 70 years old or older (*N* = 4,373).

[3]Provided upon request are the results for statistical models in which all of the battery VTP scores were included in the same equation. All of the remaining battery VTP scores were added to selected models in which one or more of the VTP terms were found to be significantly different from zero. Addition of the remaining battery VTP scores did not diminish the significance levels of the original VTP terms.

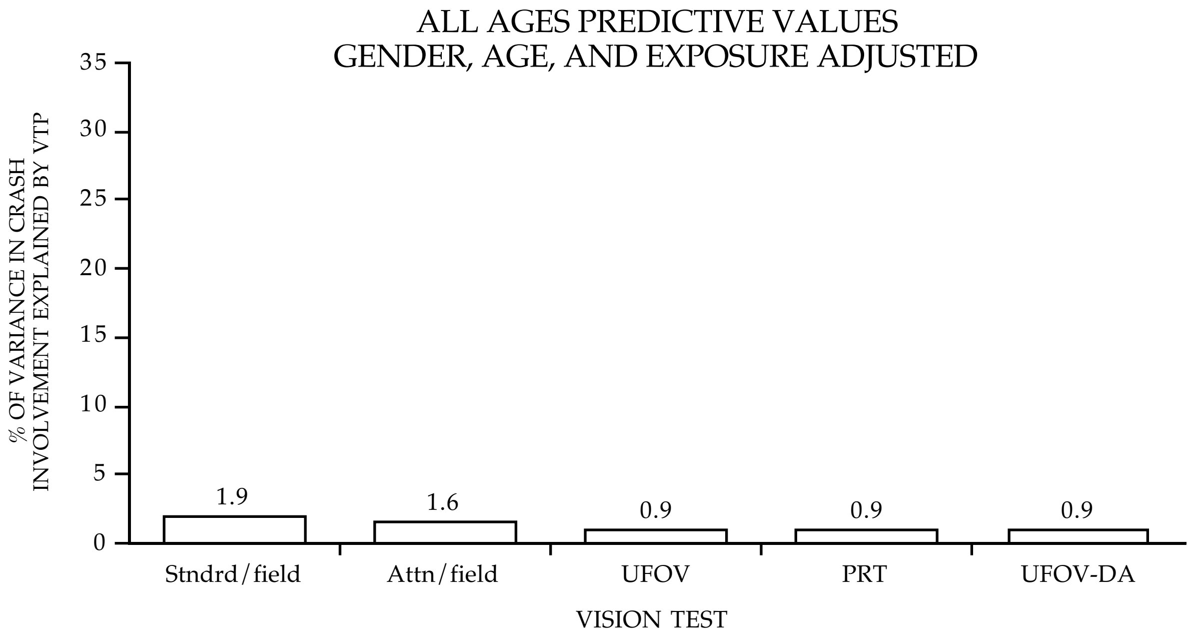


Figure 11. Percentage of variance in crash involvement explained by vision test performance (VTP) for all age groups combined after adjusting for gender, age, and exposure.

As was also noted in connection with Figure 10, the significant result for the standard field test in Figure 11 is surprising in that there was relatively little loss and little variation in standard field integrity as measured by the Synemed modified Optifield II (see Figure 7). However, these results are consistent with those found by Johnson and Keltner (1983) in a large-scale California study. They found that drivers having a visual field loss in both eyes (1.1% of the 10,000 volunteers tested at the El Cerrito and Redwood City field offices) had a mileage-adjusted crash rate for the 3-year period prior to testing that was twice that of an age- and gender-matched control group with normal visual fields.

Finding an association between VTP and crashes for the tests measuring visual field, visual attention, and perceptual reaction time is consistent with the results of detailed crash analyses which have shown that the most frequent cause of crashes is inadequate or improper visual search: failing to look adequately or altogether when the traffic situation requires a distinct visual surveillance activity for safe completion of the driving task (Treat et al., 1979). Most lookout errors occur while maneuvering through an intersection, e.g., while making a left turn. The failure to find a significant association between crashes and contrast sensitivity for all ages combined could be due to variation in this ability becoming critical to driving at advanced age and primarily during night driving.

Study Question 6:
Is VTP more predictive of crashes for certain age groups after statistically adjusting within each age group for gender, age, and amount of exposure?[4]

Even without knowing about the widely differing performances of the 70+ year old drivers on the Visual Attention Analyzer tests and on the Synemed attentional test, one might expect a priori that the predictive value of the vision test scores shown in Figure 11 would be enhanced for older drivers in particular. One might expect enhanced VTP predictive value for 70+ year olds because of age-related constraints on compensation for impaired visual abilities. Generally, it probably takes few (possibly only one) vision-related citations or crashes to motivate and educate a driver to more or less properly restrict their driving or otherwise compensate for their impaired visual ability. Consequently, vision-related driver record activity will generally be slight up to the ages when, on average, compensation is likely to be less than wholly adequate for worsening impairments of multiple visual abilities critical to safe driving. Normal age-related declines in vision functioning generally begin at about age 50, while disease-related declines commence around age 65 (Janke, 1994). Failure to yield the right-of-way, noted by Janke (1994) as possibly a failure of detection, is the primary cause of older drivers' crashes as early as age 50. Right-of-way violations or disobeying signs and signals are the primary collision factors for 42% of the fatal/injury crashes of drivers ages 60-69 and 57% of those drivers aged 80 and above (Gebers, Romanowicz, & McKenzie, 1993). And finally, as drivers age, their unadjusted fatal/injury crash involvement decreases through about age 69 and then gradually rises, while their mileage-adjusted fatal/injury crash rate decreases through about age 64 and then sharply rises (Gebers, Romanowicz, & McKenzie, 1993).

Figure 12 shows, as expected for the older drivers, enhanced predictive value for total UFOV, UFOV loss associated with divided attention, and perceptual reaction time as measured with the Visual Attention Analyzer, but not enhanced predictive value for the two Synemed visual field measures. After adjusting for gender, age, and amount of exposure, VTP was not found to be predictive of crashes for subjects in the other three age groups.

[4]In order to determine whether the association of poor VTP with crashes might be significantly stronger for certain age groups, VTP by age group interaction terms were added to the regression model used in answering the last question. If the p-value of the regression coefficient for one or more of the VTP by age group interaction terms was .200 or less, then the regression model used for all age groups combined was evaluated for the indicated age groups.

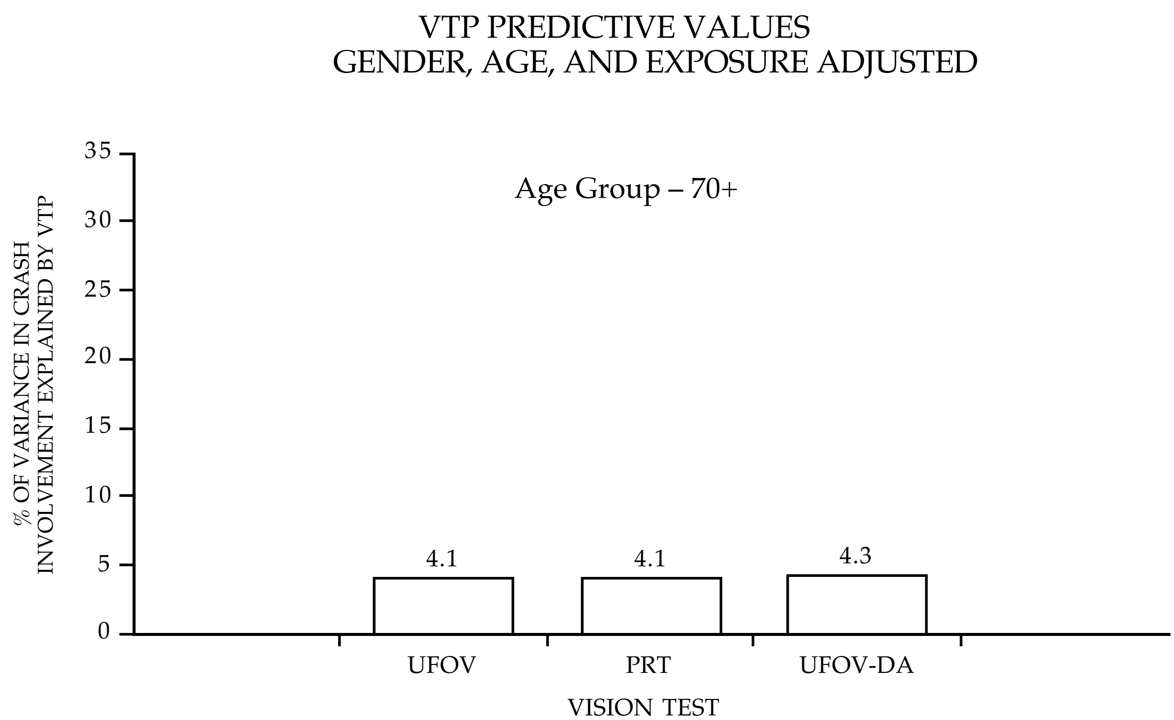


Figure 12. Percentage of variance in crash involvement explained by vision test performance (VTP) for the oldest age group (70+) after adjusting for gender, age, and amount of exposure.

Why the two Synemed visual field measures were not shown to have at the least a small amount of predictive value for the oldest age group, when they did for all ages combined, may be due to the much lower statistical power (ability to detect a relationship when one exists) of the within-age group analysis compared to that of the combined-age group analysis. Statistical power is strongly dependent upon sample size, and the sample size of the oldest age group was only about 25% of the total number of subjects. Reduced statistical power may also be why VTP was not found to be predictive of crashes for subjects in the other three age groups. An additional reason why the two Synemed visual field measures were not shown to have predictive value for the oldest age group might be that older drivers <u>on average</u> can still adequately compensate for losses in visual field integrity.

In summary, the results provide evidence that age moderates the relationship between crashes and the three Visual Attention Analyzer measures, namely, total UFOV loss, UFOV loss associated with divided attention, and perceptual reaction time. The association of crashes with these three VTP measures was stronger for the 70+ year old renewal applicants.

Study Question 7:
To what extent do poor-vision drivers and older drivers self-restrict? How does the magnitude of self-restriction vary with VTP and age?

No vision test has to date successfully yielded VTP that explains more than 5% of the differences in crash rate among drivers representative of the general driving population or of specific age groups (Owsley & Ball, 1993). Compensation for reduced visual ability by self-restricting is perhaps the most common reason suggested for why one should expect to find only a weak relationship between VTP and crashes. If drivers with poor vision tend to avoid driving under those visually demanding conditions that increase their exposure to crash risk, then the association of poor VTP with crashes would be expected to be weak.

The Driving Habits Survey administered in this study measured the driver's level of self-restriction (never, sometimes, often, or always) for a variety of forms of self-restriction: night-driving frequency, avoidance of rain or fog, avoidance of sunrise or sunset, avoidance of driving alone, avoidance of left turns, and avoidance of heavy traffic. Scores on the five avoidance measures were combined into a general self-restriction measure called AVOIDANCE. Table 5 indicates the extent to which poor vision scores and driver age were found to be associated with the reported level of self-restriction. All the indicated associations are modest; neither VTP nor age explained more than 7% of the differences in self-restriction. In general, loses in visual ability were, on average, associated with reduced night driving and avoidance of rain or fog, sunrise or sunset, driving alone, and left turns. Avoidance of heavy traffic was only associated with the Visual Attention Analyzer measures: UFOV loss (both total and UFOV-DA) and PRT. Avoidance of sunrise or sunset was found to be especially associated with losses in contrast sensitivity, attentional field, and UFOV. Of the measured visual abilities, losses in UFOV (both total and UFOV-DA) were most highly associated with self-restriction.

Table 5

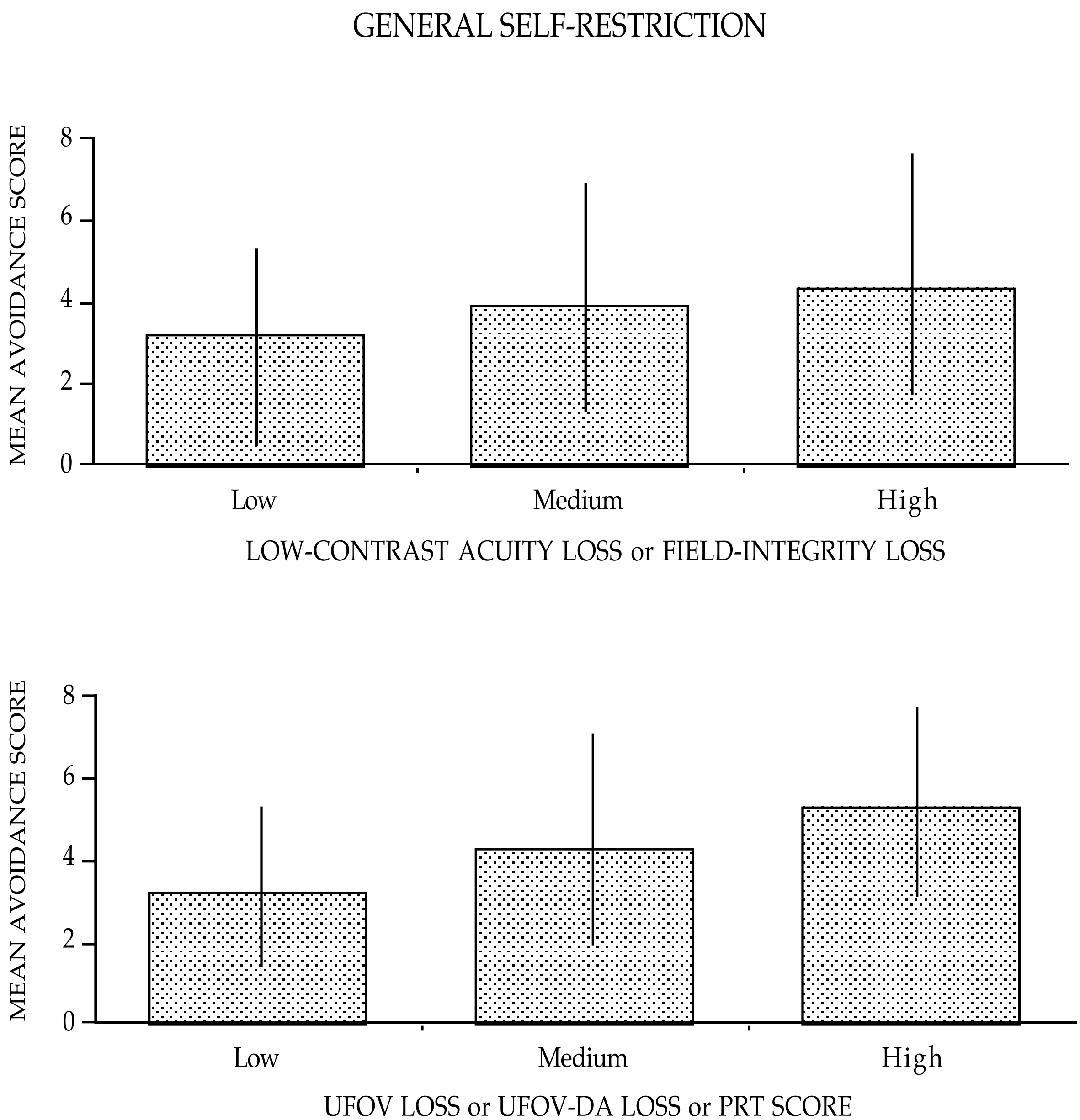
Association of Self-Restriction with Poor VTP and Driver Age

	Night driving frequency	Avoidance of					AVOIDANCE
		Rain or fog	Sunrise or sunset	Driving alone	Left turns	Heavy traffic	
Snellen fail	+	+	+	+	+		+
P-R L-C A	+	+	++	+	+		+
SKILL-HC	+	+	+	+	+		+
SKILL-LC	+	+	++	+	+		+
BGT-off	+	+	+	+	+		+
BGT-on	+	+	++	+	+		+
Stndrd/field	+	+	+		+		+
Attn/field	+	+	++	+	+		+
UFOV	++	++	++	+	+	+	++
UFOV-DA	+	++	++	+	+	+	++
PRT	+	+	+	+	+	+	+
Age	++	+	++	+	+		+

Note. One or two pluses indicates a statistically significant association of self-restriction with VTP or Age (the worse the visual ability or the older the driver, the more self-restriction). Two plusses indicate that 5% or more of the variation in the reported level of self-restriction was explained by VTP or Age. One plus indicates that less than 5% of the differences in self-restriction was explained by VTP or Age. AVOIDANCE is a composite measure and is comprised of the five avoidance scores.

Older driver ages were also generally associated with self-restriction except for avoiding heavy traffic. As one might expect, older drivers reported especially avoiding driving at night and at sunrise or sunset.

Figure 13 illustrates the mean levels of self-restriction for low, medium, and high losses in the visual abilities measured in this study. Figures 14 illustrates the mean level of self-restriction for each of the four age groups. Reported level of self-restriction was highly variable both with respect to visual ability loss and age, as indicated by the vertical lines in Figures 13 and 14. One source of this variability may be drivers varying in the extent to which they are having to compensate for multiple visual and non-visual impairments. In general, the mean reported level of self-restriction is low, corresponding to a value between never avoiding and sometimes avoiding (closer to sometimes than to never). Only subjects with a high UFOV loss (both total and UFOV-DA) or a long perceptual reaction time reported sometimes self-restricting.



Note. The mean levels of avoidance for low, medium, and high losses in the contrast sensitivity and field integrity measures were about the same and therefore are represented in one graph (top). The same explanation applies to the single representation in the bottom graph for the Attention Analyzer measures. Vertical lines represent plus and minus 1 standard deviation from the mean. About two-thirds of normally-distributed data fall in this interval. Maximum AVOIDANCE score = 15. Low visual-ability loss = lower 70% of loss scores; high visual-ability loss = highest 10% of loss scores.

Figure 13. Mean AVOIDANCE score by level of visual ability for the contrast sensitivity, field integrity, and Attention Analyzer measures.

Note. Vertical lines represent plus and minus 1 standard deviation from the mean. About two-thirds of normally-distributed data fall in this interval. Maximum score = 15.

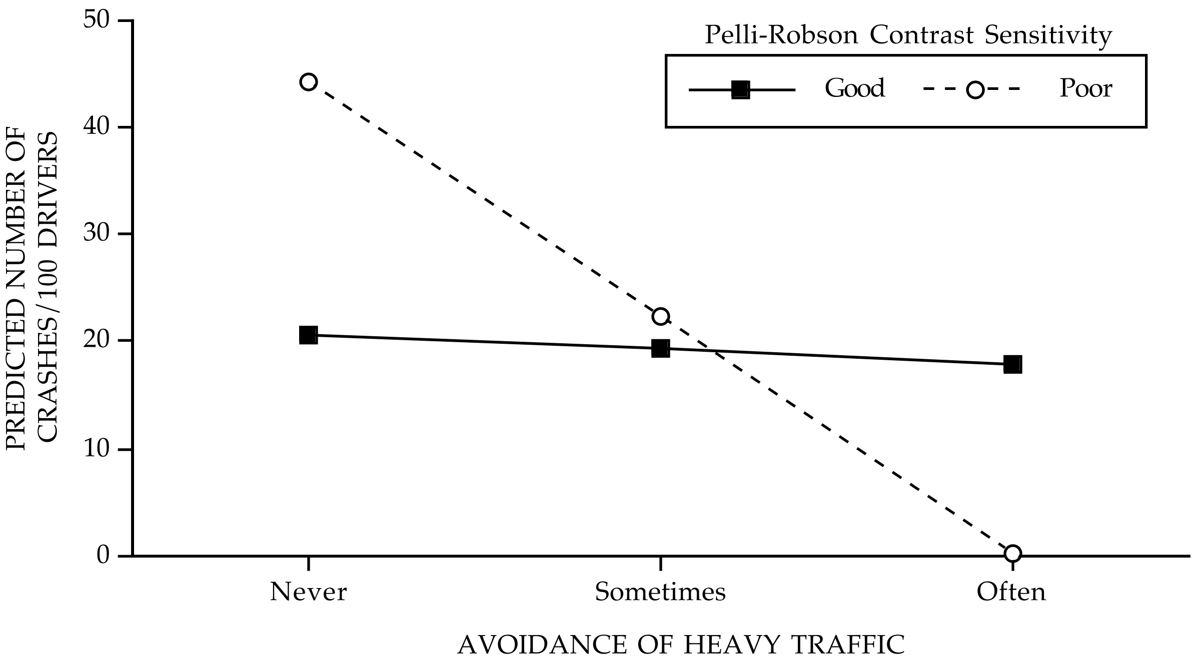
Figure 14. Mean AVOIDANCE score by age group.

Although level of self-restriction may be only marginally related to age and declining VTP, the correlations may be sufficient to obscure or attenuate the intrinsic relationship between VTP and crash risk. This question is explored in the next section.

Study Question 8:
Is the relationship between VTP and crashes moderated (mediated) by self-restriction?
A specific form of self-restriction could be said to moderate the relationship between VTP and crashes (see Figure 1) if the strength of the association of poor VTP with crashes was significantly weaker or stronger for higher versus lower levels of self-restriction. Whether there were significant differences in the association of poor VTP with crashes at different levels of self-restriction was statistically assessed for each form of self-restriction measured in this study. Figure 15 illustrates for drivers aged 26-39 how the association of poor Pelli-Robson low-contrast acuity with crashes is moderated by the reported level of restriction from driving in heavy traffic. Drivers who have poor contrast sensitivity and who never avoid driving in heavy traffic are predicted to have an elevated crash rate relative to drivers with good contrast sensitivity. However, the reverse (very low crash risk) is predicted for drivers who have poor contrast sensitivity and who often avoid driving in heavy traffic. Avoiding heavy traffic appears to compensate at least in part for poor contrast sensitivity. Consequently, the predicted crash rate would be about the same for the drivers with poor and for the drivers with good contrast sensitivity when averaged across all levels of heavy traffic avoidance. However, when measured with regard to the levels of heavy traffic avoidance, the

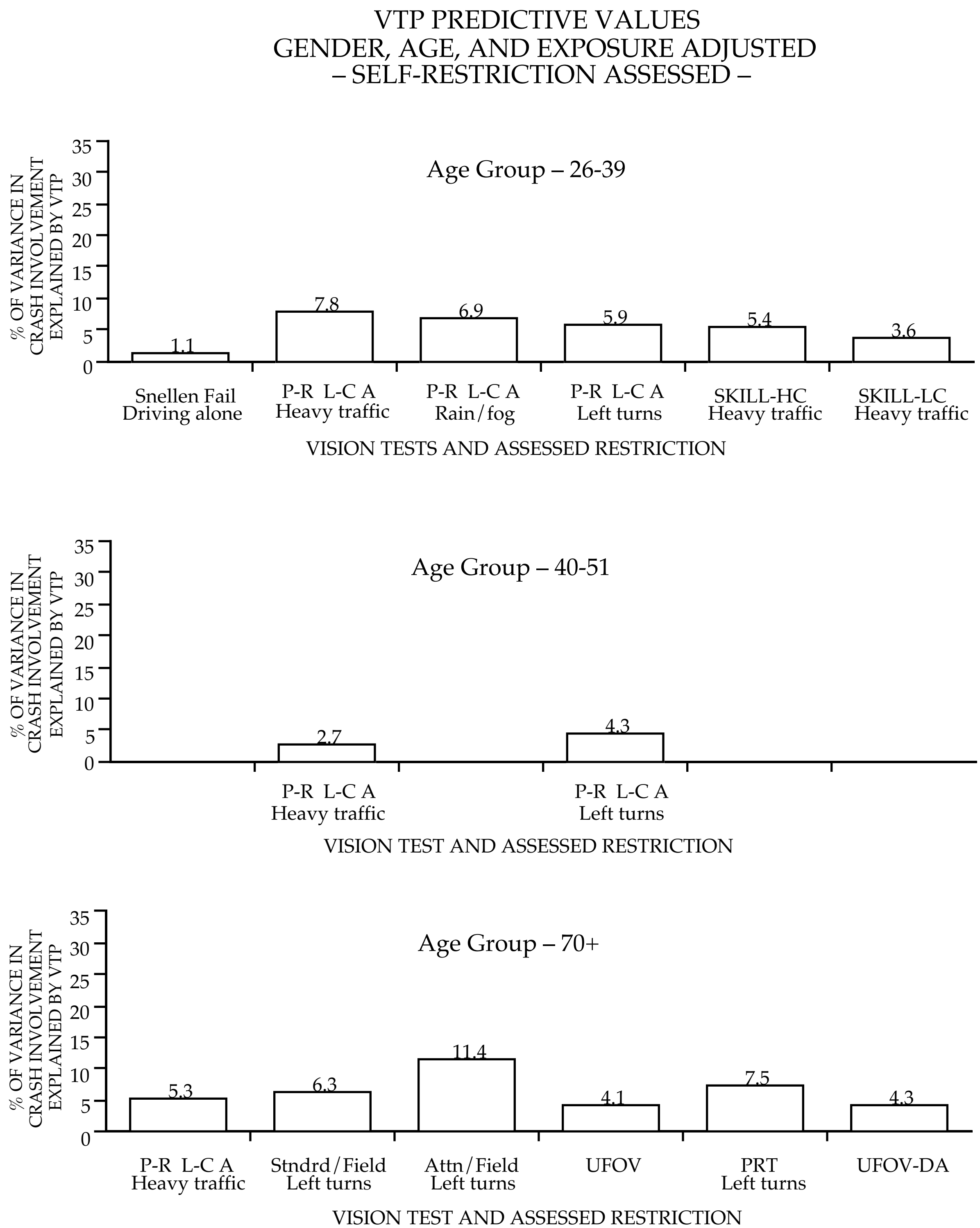
strength of the association of poor Pelli-Robson low-contrast acuity with crashes will be enhanced to the extent that drivers with poor Pelli-Robson low-contrast acuity do not avoid heavy traffic.

Figure 16 shows by age group the enhanced predictive values of performance on the following tests when VTP predictive values were measured with regard to the level of the indicated forms of self-restriction: DMV Snellen test, Pelli-Robson low-contrast acuity test, the Smith-Kettlewell Low Luminance Card, the visual field tests, and the first Visual Attention Analyzer test. The reader may wish to compare Figure 16 with Figure 12, which shows the significant VTP predictive values when measured without regard to the level of self-restriction. Appendix D summarizes the hierarchical multiple regression equations indicating the moderating effect of self-restriction.



Note. Predicted values are based on a small sample size (n = 335), and therefore should be regarded only as rough approximations.

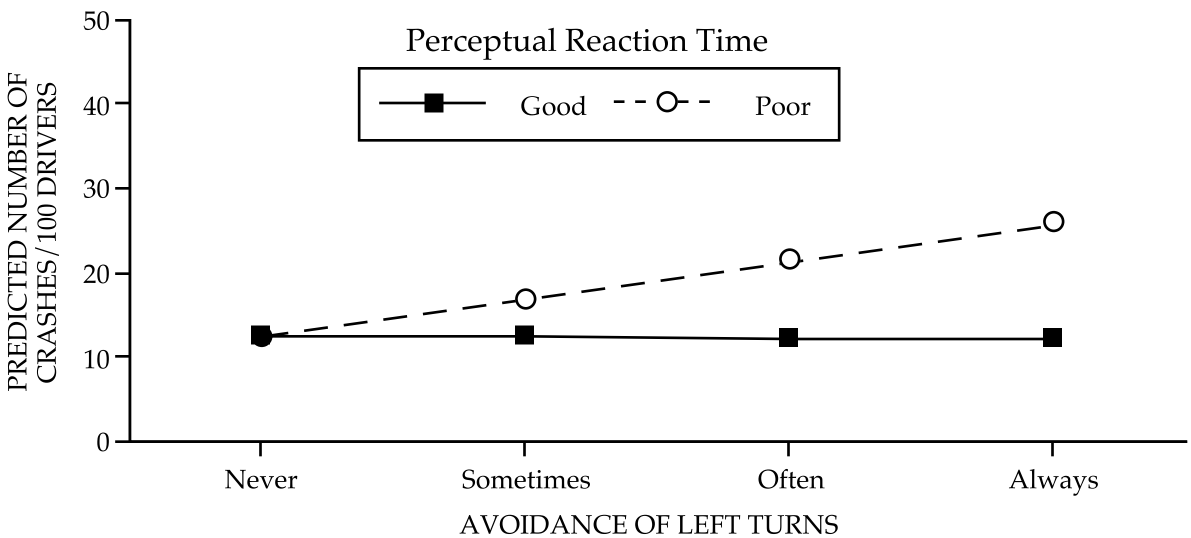
Figure 15. Predicted number of crashes over a 3-year period for drivers aged 26-39 by Pelli-Robson low-contrast acuity and level of avoidance of heavy traffic.



Note. UFOV and UFOV-DA predictive values were not moderated by any of the forms of self-restriction measured in the study.

Figure 16. VTP predictive values by age group when moderated by the indicated form of self-restriction and after adjusting for gender, age, and amount of exposure.

For 70+ year old drivers, avoiding left turns significantly moderated the relationship between crashes and standard and attentional field-integrity losses and perceptual reaction time. However, avoiding left turns was not predictive of fewer crashes for drivers in this age group with poor standard or attentional visual fields or poor perceptual reaction time. Instead, as illustrated in Figure 17 for perceptual reaction time, older drivers who have poor standard or attentional visual fields or poor perceptual reaction time and who often or always avoid left turns are predicted to have a higher crash rate relative to drivers who have good visual fields or good perceptual reaction time. This result is consistent with the inadequate-compensation hypothesis presented earlier for 70+ year old drivers. Older drivers' compensation is on average likely to be less than wholly adequate for worsening impairments of multiple visual abilities critical to safe driving. Older drivers with the worse measured perceptual reaction times and other visual and non-visual driving-related impairments are the ones most likely to report often or always self-restricting. If, as posited, the self-restricting of these drivers is inadequate, then the association of poor visual ability with crashes will be greater for higher levels of self-restricting. Contrary to the inadequate-compensation hypothesis, avoiding heavy traffic appears to compensate at least in part for the reduced contrast sensitivity found in the older drivers. A possible explanation is offered below.



Note. Predicted values are based on a small sample size (n = 277), and therefore should be regarded only as rough approximations.

Figure 17. Predicted number of crashes over a 3-year period for drivers aged 70+ by perceptual reaction time and level of avoidance of left turns.

Low-contrast acuity having predictive value for 26-39 year old drivers may be due in part to what Schieber (1988) calls the contact lens syndrome. Extended wearing of contact lenses can result in impaired vision functioning under low-contrast conditions (Applegate & Massof, 1975). After wearing contact lenses for extended periods of time, individuals may report blurred or foggy vision even though their visual acuity, as measured on a conventional high-contrast chart has not changed. However, their performance on a contrast sensitivity test reveals their impaired vision. Because drivers who have contact lens syndrome do not have reduced visual acuity, and therefore have no trouble reading traffic signs or making out details, they will commonly not be aware of their reduced visual ability and so will not modify their driving accordingly. Extended contact lens wear may reduce contrast sensitivity in at least two related ways: (1) the accumulation of scratches on the lenses causes light-scatter inside the eye and thereby introduces a veiling haze onto the retinal image, and (2) extended wear can induce corneal edema which also causes light-scatter inside the eye.

The apparent waning in the predictive value of Pelli-Robson low-contrast acuity for driver ages 40-51 is consistent with contact lens wear diminishing with an increasing need for bifocals by individuals in their 40s. It must be stressed that the above hypothesis is highly speculative, particularly since habits in the use of contact lenses was not measured.

Pelli-Robson low-contrast acuity having predictive value for 70+ year old renewals may also be due at least in part to drivers not driving in accordance with their reduced visual ability because of a lack of awareness of their visual ability loss. Low-contrast acuity loss in 70+ year old drivers may be due to cataracts, glaucoma, or retinal degeneration. These age-related visual disorders differentially impact contrast sensitivity and visual acuity. In the early stages of these disorders, contrast sensitivity is likely to be impaired, but not visual acuity. Consequently, a driver may develop one of these disorders and continue to drive for several years before diagnosis, unaware of their worsening contrast sensitivity (Schieber, 1988).

In summary, different forms of self-restriction were found to moderate the relationship between crashes and performance on the DMV Snellen test, Pelli-Robson low-contrast acuity test, the Smith-Kettlewell Low Luminance Card, the visual field tests, and the first Visual Attention Analyzer test (PRT assessment). VTP predictive values were enhanced when these moderating influences were accounted for in the prediction models.

Study Question 9:
Is there any evidence of other variables moderating (mediating) the relationship between VTP and crashes?

One might expect, a priori, enhanced VTP predictive values for renewal applicants who fail the department's Snellen test. Many of the Snellen fails will pass the Snellen test after getting corrective lenses or updating their corrective-lens prescriptions. Others, however, will not be able to pass the department's Snellen test even with best-corrected visual acuity. These will most likely be 70+ year old drivers. Older drivers whose best-corrected visual acuity is not sufficient to read a line of 20/40 letters have more wrong with their vision than impaired ability to see details (Bailey & Sheedy, 1988). They would most likely also have one or more of the following age-related vision disorders:

cataracts, macular degeneration, other retinal pathology such as diabetic retinopathy, or glaucoma. If so, contrast sensitivity, glare resistance, and light sensitivity would all also likely be substantially impaired. Glaucoma and diabetic retinopathy may also impair visual fields. Consequently, among Snellen fails one might expect that poor VTP would be more strongly associated with crashes than it would be among Snellen passes due to Snellen fails on average being unable to wholly compensate for all of their impaired visual abilities.

About 65% of the Snellen test fails were 70+ year old drivers. Table 6 shows the fairly even distribution of Snellen test fails across the three test batteries. Almost 10% of the study subjects failed the department's Snellen test, whereas approximately 25% of the older drivers failed (see Figure 3).

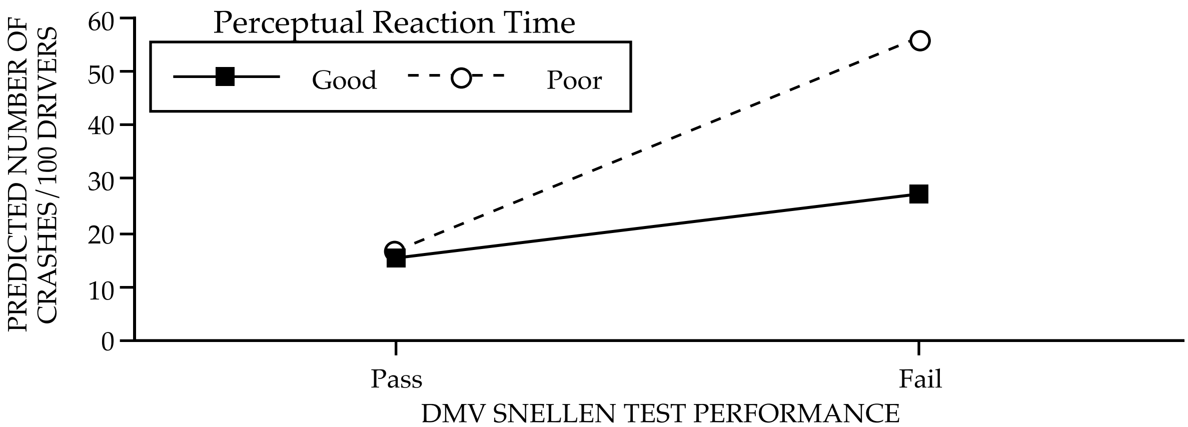
Table 6

Number and Percentage of Subjects who Passed and Failed the Department's Snellen Test by Vision Test Battery

	Vision test battery			
Snellen test result	SK1	SK2	UFOV	Total
Pass	1,126 91.6%	993 91.5%	1,068 87.8%	3,187 90.3%
Fail	103 8.4%	92 8.5%	148 12.2%	343 9.7%
Total	1,229	1,085	1,216	3,530

Appendix C contains summaries of six hierarchical multiple regression analyses which indicate that poor VTP is more strongly associated with crashes for subjects who failed the department's Snellen test than for those who passed it. This moderation of the relationship between VTP and crashes by performance on the department's Snellen test is illustrated for perceptual reaction time in Figure 18. For subjects who passed the Snellen test, there was no difference between the number of predicted crashes for drivers with poor perceptual reaction time and drivers with good perceptual reaction time. However, for subjects who failed the Snellen test, those who had poor perceptual reaction times were predicted to have an elevated crash rate relative to those having good perceptual reaction times.

The one SK1 test on which performance was <u>not</u> more strongly associated with crashes when the Snellen test was failed was the high-contrast SKILL Card chart, which only differs from the Snellen test in being a near- rather than far-acuity test. The other three test scores for which VTP predictive value was not enhanced were standard and attentional field-integrity loss and the UFOV loss associated with divided attention. Both measures of divided attention require the subject to perform a peripheral task while simultaneously performing a central task. Perhaps compensation for impaired ability to divide attention is not exacerbated by the conditions underlying the inability to read a 20/40 line.



Note: Predicted values are based on a small sample size (n = 1,197), and therefore should be regarded only as rough approximations.

Figure 18. Predicted number of crashes over a 3-year period for all age groups combined by perceptual reaction time and pass/fail performance on the department's Snellen test.

In reviewing the regression results, it was surprising to discover that two of the equations revealed that failing the department's Snellen test is significantly and substantively associated with crashes. See equations for Visual Attention Analyzer UFOV loss and perceptual reaction time (Appendix E-5 and E-6). The predictive value of the Snellen test is illustrated in Figure 18 by the elevated rate of crashes predicted for Snellen fails among drivers with both poor and with good perceptual reaction times. These results suggest that the predictive value of the Snellen test is generally masked by differences in stronger higher-order visual determinants of crashes, such as PRT and UFOV. In other words, the validity of the department's 20/40 Snellen test becomes evident when differences in higher order perceptual or attentional abilities are statistically "removed."

Figure 19 shows for the Snellen fails (all age groups combined) the enhanced VTP predictive values of the SKILL Card low-contrast chart, the Berkeley Glare Tester chart in the absence of glare, and the Visual Attention Analyzer (total UFOV & PRT). The reader may wish to compare Figure 19 with Figure 11, which shows the significant predictive values for all the subjects, and Figure 12, which shows the significant predictive values for only the 70+ year old subjects. The predictive values for the Snellen fails' total UFOV loss and PRT are about double what they are for 70+ year old subjects. Additionally, for the Snellen fails, the predictive value of low-contrast near-acuity is about double that estimated for the two higher-order visual abilities. This was true for low-contrast near-acuity as measured with the SKILL Card chart and as measured with the BGT chart. These results suggest that of drivers who fail the department's Snellen test, those who also have poor low-contrast near-acuity are more likely to be involved in crashes than are those who do not.

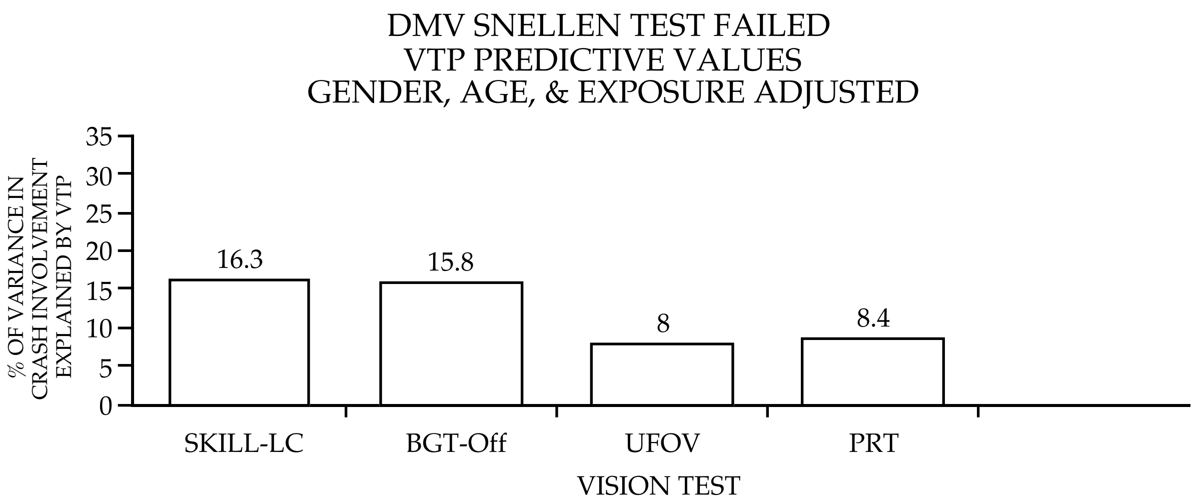


Figure 19. Percentage of variance in crash involvement explained by Vision Test Performance (VTP) for Snellen test fails for all age groups combined after adjusting for gender, age, and amount of exposure.

Figure 20 shows for the Snellen test fails (all age groups combined) the enhanced predictive value of performance on each of the following tests when VTP predictive values were measured with regard to the level of the indicated forms of self-restriction: Pelli-Robson low-contrast acuity test, SKILL Card low-contrast chart, Berkeley Glare Tester, and the Visual Attention Analyzer (total UFOV & PRT). Predictive values for low-contrast acuity and perceptual reaction time are especially notable (Peck, 1993). Also note that the predictive value of perceptual reaction time is about double that of total UFOV loss for Snellen test fails who reported little or no night driving, avoidance of sunrise or sunset, and/or avoidance of heavy traffic. The reader may wish to compare Figure 20 with Figure 16, which shows analogous VTP predictive values for subjects in general. Poor performance on all of the indicated tests was to some extent "compensated for" by the indicated form of self-restriction. Figure 21 illustrates for poor perceptual reaction time its apparent compensation by low night driving frequency.

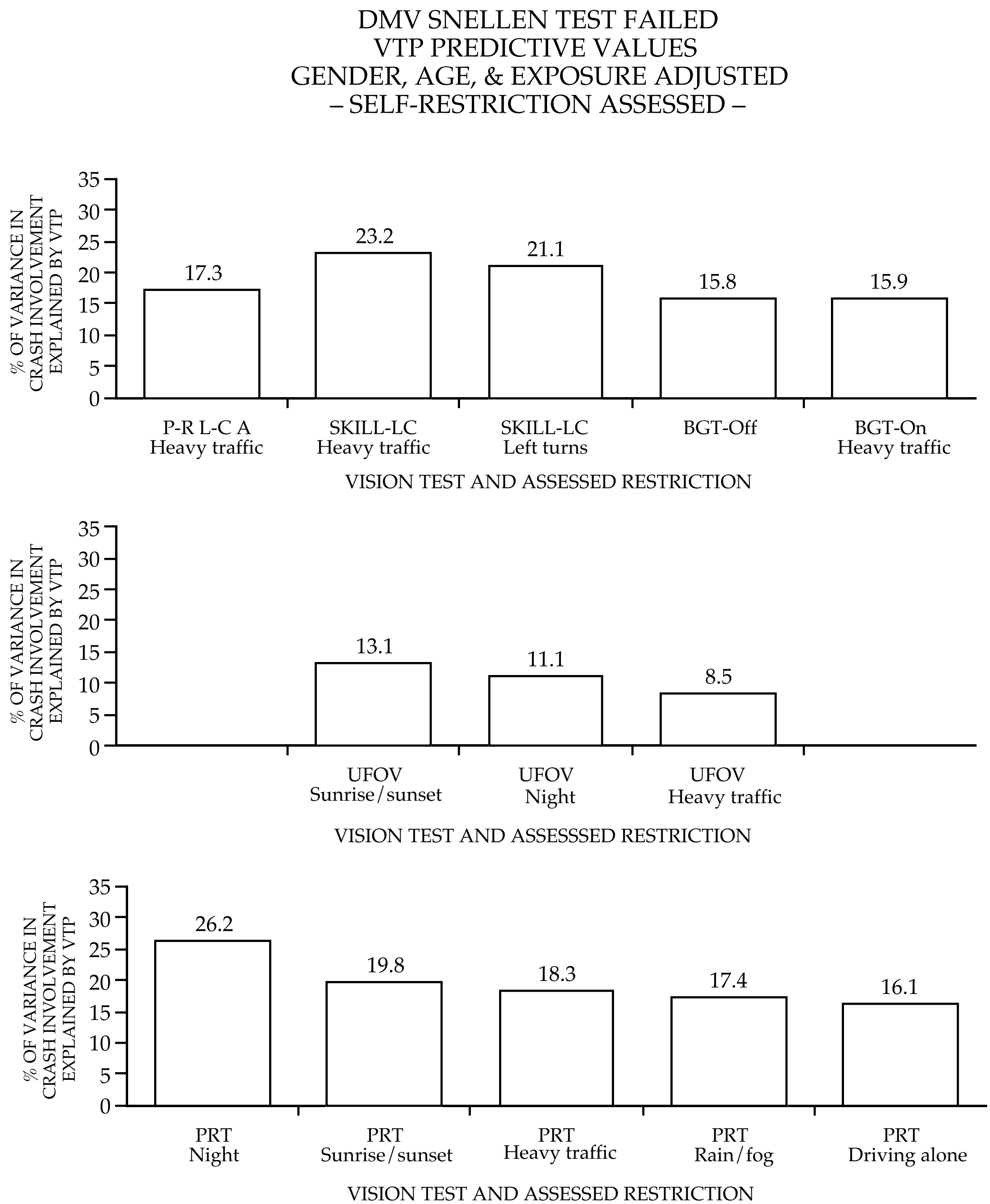
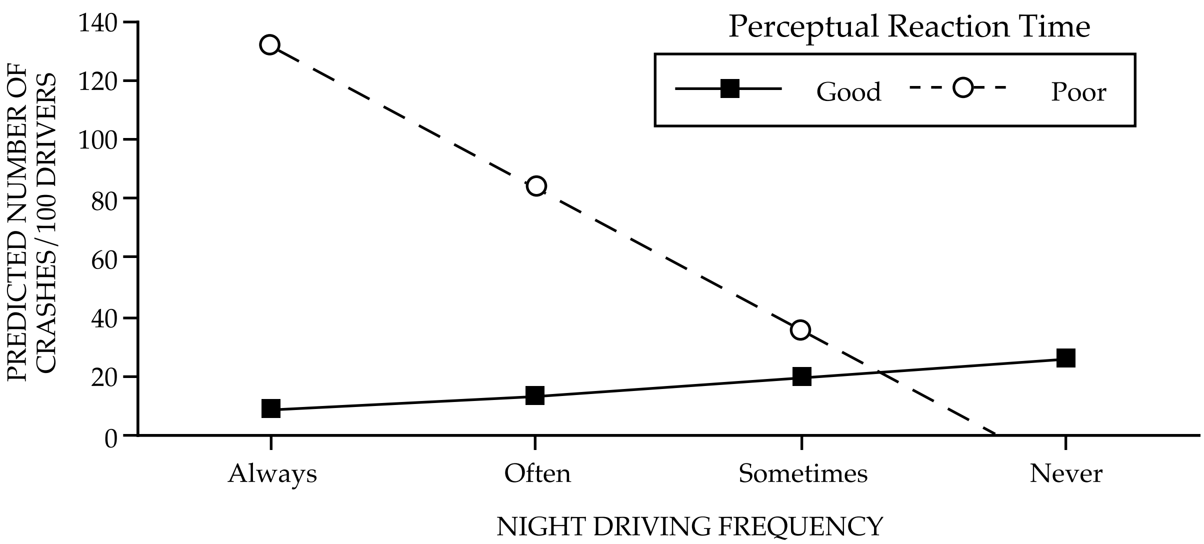


Figure 20. Percentage of variance in crash involvement explained by Vision Test Performance (VTP) for Snellen test fails for all age groups combined when moderated by the indicated form of self-restriction and after adjusting for gender, age, and amount of exposure.



Note. Predicted values are based on a small sample size (n = 143), and therefore should be regarded only as rough approximations.

Figure 21. Predicted number of crashes over a 3-year period for Snellen test fails for all age groups combined by perceptual reaction time and night driving frequency.

In summary, VTP predictive values for contrast sensitivity, total UFOV, and perceptual reaction time are 2 to 3 times higher for renewals who failed the DMV Snellen test than they are for renewals in general. It was also discovered that failing the department's Snellen test was substantively associated with crashes when the effects of higher-order perceptual or attentional abilities were removed.

Study Question 10:
What are the operational and policy implications of the results?
Which of the experimental vision tests offer the most promise? As stated in the Introduction, the objective of the present study has been to isolate those vision tests showing the most promise for further validation in a large-scale statewide study. In terms of Peck's (1986) risk-management model of driver control, "promise" has been evaluated with respect to risk assessment–the identification of high-risk drivers. However, as noted by Peck, the net impact of a given safety policy is a function of several parameters. Once a high risk group is identified there must be developed countermeasures for reducing that risk through remediation, license controls, and in some instance, delicensure. Another important parameter is volume. All other things being equal, a countermeasure applied to a large number of high-risk drivers will prevent more crashes than a countermeasure applied to a small number of high-risk drivers. Finally there must be a consideration of benefits and costs to determine whether the added tests and test time are cost-justified. Benefits and costs depend upon test validity, equipment and staff time requirements, including that needed for any follow-up assessment, the effectiveness of the countermeasures, and the number of individuals to be tested. These factors are briefly discussed below.

Test validity. From the standpoint of crash predictive validity, the Pelli-Robson low-contrast acuity test and PRT assessment as measured by the Visual Attention Analyzer offer immediate promise for improving the department's identification and regulation of drivers having impaired visual abilities critical to safe driving. As noted earlier, PRT is a better predictor of crashes than the Visual Attention Analyzer total UFOV score.

Performance on the department's Snellen test was also found to be predictive of crashes for certain subgroups of drivers.

Cost of equipment and staff. The Pelli-Robson chart is commercially available, quick (about 1.5 minutes), and easy to administer. When purchased singly, a Pelli-Robson chart costs $300.

Measuring PRT would be possible using a much simpler testing apparatus than the Visual Attention Analyzer and would take only 4-5 minutes. A PRT screener test would need to be developed to measure the subject's information process speed. A number of commercially available PC-based tests exist which measure perceptual reaction time. It would also be a simple matter to develop a PC-based test that duplicates the PRT measure contained in the Visual Attention Analyzer UFOV test.

The cost of follow-up assessment of drivers performing marginally on the vision tests would also need to be considered. Follow-up assessment may include collection and review of a DL 62 form completed by a vision specialist. A road test might also be indicated if the DL 62 indicates a serious vision condition or the applicant only marginally passes the vision test.

Treatments/countermeasures - remedial/graded licensing. Implementation of a new vision test would probably be most effective in minimizing crashes and maximizing mobility if implementation included (1) feedback about vision test performance, (2) counseling for marginally-passing license applicants about remediation and/or compensation, (3) appropriate license restrictions (conditions) and guidelines for their application, and (4) guidelines for suspending, revoking, or not licensing unsafe drivers, that is, drivers who can not adequately compensate or who cannot be improved through remediation. These treatments and countermeasures would in turn need to be integrated into a structured remedial/graded licensing program as proposed by Janke (1994). The general purpose of such a program would be to systematically help impaired drivers retain their driving privileges as long as practicable through the use of various forms of compensation. In developing a remedial/graded licensing program, it is important to keep in mind the constraints on adequate compensation listed in the Introduction.

Losses in contrast sensitivity and PRT cannot be directly remediated like losses in visual acuity. However, other means of remediation are available. In the case of contrast sensitivity, remediation might include referring the applicant to a vision specialist for diagnosis, assessment, and treatment of the visual disorders known to cause losses in contrast sensitivity, for example, extended contact lens wear, cataract, and glaucoma (Schieber, 1988). The latter two disorders are progressive and also affect other vision functions critical to safe driving, such as glare resistance and light sensitivity. Low-contrast acuity screening would facilitate the early detection of these disorders and thereby make possible their early treatment. Treatment would usually be a matter of arresting the progression of the disorder which in turn would improve expected driver safety and mobility; the earlier the treatment, the more potential for improvement (Schieber, 1988, 1994).

Losses in PRT may also be remediated by treating underlying disorders. There is also evidence that losses in the abilities underlying visual attention may be remediated by training (Ball, Beard, Roenker, Miller, & Griggs, 1988). Using the Visual Attention Analyzer as a training device, the subjects, who were divided into three age groups (young, middle aged, and older), were trained on tasks similar to those described earlier for the UFOV test. All three age groups were found to significantly improve their performance on both the central task and the peripheral-localization task. Ball et al. (1988) concluded that age-related shrinkage in UFOV can be reversed at least partially by a relatively small amount of practice. An alternative to the Visual Attention Analyzer as a training device may be found in devices sometimes referred to as sports-vision trainers. One type of sports-vision trainer being developed is a pair of electronic spectacles. Electronics embedded in the frames of the eye-wear allows the user to vary the frequency at which the lenses alternate between clear and opaque. These electronic spectacles allow the user in effect to "exercise" their PRT.

Is there justification for age-based selective testing? The costs of test administration and follow-up treatment could be reduced by implementing one or more of the experimental vision tests on a selective basis. For example, the new tests could be given to only older drivers or only Snellen fails. However, as indicated earlier, reducing the size of the target group would also decrease potential benefits in terms of statewide reduction in motor vehicle crashes. Even if age-based selective testing were empirically defensible, as may be the case for confining PRT assessment to older drivers, it would likely be controversial. On the other hand, only assessing PRT in drivers who have failed the Snellen test would be largely functionally equivalent to selectively testing older drivers (because most of the Snellen fails are older), and at the same time failing the Snellen test is a compelling rationale for additional vision testing (as opposed to a controversial position). Confining PRT assessment to Snellen fails will also be more cost-effective because the number of Snellen fails (about 10% of the renewals) is about one-third the number of renewal applicants 70+ years old (about 25% of the renewals), and more importantly, the predictive validity of the PRT for Snellen fails is twice that of subjects aged 70+.

In contrast to PRT assessment, the results of this study indicate that Pelli-Robson low-contrast acuity testing would best serve California drivers if it were routinely administered to all renewal applicants instead of to only older drivers or Snellen fails. As indicated earlier, routine low-contrast acuity screening would facilitate the early detection of progressive visual disorders, and therefore, make possible their early treatment before the visual disorder causes loses in visual acuity.

In considering the operational and policy implications of using Pelli-Robson low-contrast acuity test scores and/or PRT test scores, it is important to keep in mind that by themselves, scores on neither of these or the other experimental tests predicted crashes with all age groups combined. PRT, however, was by itself predictive of crashes for subjects 70+ years old. Nonetheless, the higher VTP predictive values associated with the Pelli-Robson low-contrast acuity test scores and the PRT test scores were derived from multivariate models in which the relationship between VTP and crashes was adjusted for covariation with other variables, such as age and exposure. This would mean that to fully realize the VTP predictive values estimated from the models evaluated in this study, one would need to adjust each vision test score in accordance with the values and weights of the other variables in the pertinent regression equation. In other words, in determining whether countermeasures need to be applied to a renewal applicant after having measured their PRT for instance, one would also score the applicant on such variables as their age and exposure. These three scores would then be combined in accordance with the pertinent regression equation in order to arrive at the adjusted PRT score. Adjusting test scores in this manner would in effect be setting different screening standards for different groups such as older and younger drivers and high and low mileage drivers. Such a departure from present departmental policy would require careful consideration by management.

<u>Are the significant results of sufficient magnitude to warrant operational use</u>? There is one result that is of sufficient magnitude to warrant operational use, namely, finding a substantive association between crashes and performance on the department's Snellen test, particularly when evaluated in conjuncture with other variables, such as age and PRT. A straight forward operational use of this finding would be to discontinue use of the Optec 1000 and the Ortho-Rater vision testers and simply give Snellen fails a copy of form DL 62 for completion by a vision specialist. The present policy of Snellen fails having to also fail on the mechanical vision testers before referral to a vision specialist saves the department follow-up assessment costs by reducing the number of license applicants failing the department's vision-screening standard. The results of this study indicate that assuming these costs would pay off in statewide crash reduction <u>if</u> effective countermeasures were applied. Full realization of any benefits would require standardizing Snellen chart lighting, (2) revising the department's Driver License Manual so as to provide a clear statement of the Snellen test screening standard and protocol, (3) maintaining strict adherence to the departments screening standard and protocol, and (4) specifying a more comprehensive and rigorous vision examination than is presently done through the DL 62 referral process.

<u>Is there a need for additional research</u>? It is recommended that the apparent risk-predictive value of Pelli-Robson low-contrast acuity and perceptual reaction time be cross-validated in a large-scale statewide study. Cross-validation is strongly recommended due to the following statistical limitations of the present study:

1. Even though the study sample size was very large by conventional statistical standards, it included applicants from only three field offices.

2. The study used linear parametric statistical techniques even though the distribution of the criterion measure, number of crashes, was non-normal and somewhat heteroscedastic. The use of ordinary least-squares multiple regression techniques with non-normal data can be justified with large *N*s (Peck & Kuan, 1983), but some of the within-group analyses might not have had sufficient *N*s to guarantee asymptotic normality. Consequently, the significance level of the regression

coefficients, particularly those based on small *N*'s (e.g., the Snellen fails), can only be regarded as approximate.

3. Because the regression model used for all age groups combined was sometimes evaluated for multiple age groups (see footnote number 2), and because these models contained interaction terms, a large number of statistical tests were performed. Consequently, the magnitude of the reported VTP predictive values and their respective significance levels may be inflated. This inflation is exacerbated by the relative infrequency of crashes, particularly among older drivers, and by the incorporation of interaction terms in the regression models.

As noted above, this study was not designed to identify a specific set of vision tests and standards for direct statewide implementation. Rather, the objective was to evaluate several test batteries for the purpose of identifying those tests offering the most potential for a large-scale demonstration project. In further validating the Pelli-Robson low-contrast acuity test and PRT assessment, other types of tests, such as ones measuring head and trunk mobility and hazard perception should also be evaluated. All the tests would be assembled into a single battery to be administered to a large sample of subjects. This will allow us to evaluate how the consequences of low vision may be amplified when the driver suffers other driving-relevant impairments. Other objectives of this follow-up validation study would include assessing test-retest reliability, systematic age norming of the tests on the California driving population, and evaluating the utility of the tests for predicting night crashes.

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APPENDIX A

Driving Habits Survey

STATE OF CALIFORNIA
DMV
DEPARTMENT OF MOTOR VEHICLES

_____ RBM$_1$ _____ CLtr$_2$ _____ RN$_3$

_____ SS$_1$ _____ Ros$_2$ _____ Car$_3$ _____ ElC$_4$

__ __ __ __ __ __ __ __ Driver license number

_____ Month _____ Day _92_ Year

DOB: _____ Month _____ Day _____ Year

___ ___ ___ LNM

DRIVING HABITS SURVEY
Class C Renewal Applicants

We are gathering information to help us improve our driver safety programs. Your help will be greatly appreciated. All information will be kept confidential and will have no influence on your driving privilege either now or in the future. **Check only one box for each question.**

1. How many days per week do you normally drive a motor vehicle?
   ❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ 6 ❑ 7
   ❑$_8$ Check here if in most weeks you do not drive.

2. How many hours per week do you spend driving?
   ❑$_1$ 0-1 ❑$_2$ 2-4 ❑$_3$ 5-9 ❑$_4$ 10-14 ❑$_5$ 15-20
   ❑$_6$ 21 or more

3. How many miles do you drive in a normal week?
   ❑$_1$ 0-9 ❑$_2$ 10-20 ❑$_3$ 21-50 ❑$_4$ 51-150 ❑$_5$ 151-250
   ❑$_6$ 251-350 ❑$_7$ 351-500 ❑$_8$ 501-1,000 ❑$_9$ over 1,000

4. How many years have you driven a motor vehicle (either in or out of California)?
   ❑$_1$ 0-3 ❑$_2$ 4-7 ❑$_3$ 8-11 ❑$_4$ 12-15 ❑$_5$ 16-19
   ❑$_6$ 20-23 ❑$_7$ 24-35 ❑$_8$ 36-47 ❑$_9$ 48-59 ❑$_{10}$ Over 59

5. How many years have you been a driver in California?
   ❑$_1$ 0-3 ❑$_2$ 4-7 ❑$_3$ 8-11 ❑$_4$ 12-15 ❑$_5$ 16-19
   ❑$_6$ 20-23 ❑$_7$ 24-35 ❑$_8$ 36-47 ❑$_9$ 48-59 ❑$_{10}$ Over 59

6. What type of driving do you most frequently do? **Check only one box.**
   ❑$_1$ To & from work ❑$_2$ Recreational ❑$_3$ Errands (shopping, appointments)
   ❑$_4$ On the job ❑$_5$ Trips out of town ❑$_6$ Check here if none apply

7. What type of street do you most frequently drive on? **Check only one box.**
   ❑$_1$ Residential streets ❑$_2$ County roads ❑$_3$ Freeways
   ❑$_4$ Non-residential city streets ❑$_5$ Check here if none apply

8. What type of street, if any, do you least often drive on? **Check only one box.**
❑1 Residential streets ❑2 County roads ❑3 Freeways
❑4 Non-residential city streets ❑5 Check here if none apply

9. Do you drive at night?
❑1 Never ❑2 Sometimes ❑3 Often ❑4 Always

10. Do you smoke when you drive?
❑1 Never ❑2 Sometimes ❑3 Often ❑4 Always

11. Do you wear glasses or contact lenses when you drive?
❑1 Never ❑2 Sometimes ❑3 Often ❑4 Always

12. Do you avoid driving when it's raining or foggy?
❑1 Never ❑2 Sometimes ❑3 Often ❑4 Always

13. Do you avoid driving at sunrise or sunset?
❑1 Never ❑2 Sometimes ❑3 Often ❑4 Always

14. Do you avoid driving alone?
❑1 Never ❑2 Sometimes ❑3 Often ❑4 Always

15. Do you avoid parallel parking?
❑1 Never ❑2 Sometimes ❑3 Often ❑4 Always

16. Do you avoid making left-hand turns across oncoming traffic?
❑1 Never ❑2 Sometimes ❑3 Often ❑4 Always

17. Do you avoid driving in heavy traffic?
❑1 Never ❑2 Sometimes ❑3 Often ❑4 Always

After you hand in this survey you may be randomly selected to take some new vision tests. These tests will take only about 15 minutes. All test results will be kept confidential and will have no influence on your driving privilege either now or in the future.

Please return your completed survey to the person at the counter window. Thank you for your help!

Designated MVFR:	❑1 GT	❑2 MW	❑3 JS	❑4 MG
	❑5 MVD	❑6 FAH	❑7 JA	❑8 EW
Selected:	❑1 Yes	❑2 Room Occupied		❑3 Exempt
Testing Status:	❑1 1	❑2 2	❑3 RTT	
Vision Test Battery:	❑1 SK1	❑2 SK2	❑3 UFOV	

APPENDIX B

Customer Reaction Survey

The first question was open ended:

What do you think about this test?

Using the scale illustrated below, the customer was asked to give a numerical response to the following three questions.

Rating Scale:
1-Definitely No, 2-Probably No, 3-Probably Yes, 4-Definitely Yes

Do you think most people would find the instructions clear, and easy to understand?

Do you think the abilities necessary to do well on this test are also important for safe driving?

Do you think it would be fair to require people to pass a test like this to get full driving privileges?

APPENDIX C

VTP Intercorrelation Matrix for Each of the Three Test Batteries

SK1

	SKILL-HC	SKILL-LC	BGT-off	BGT-on	Snellen Fail
P-R L-C A	0.448	0.648	0.641	0.737	0.375
SKILL-HC		0.758	0.723	0.612	0.281
SKILL-LC			0.851	0.828	0.369
BGT-off				0.843	0.358
BGT-on					0.386

SK2

	Attn/field	Snellen Fail
Stndrd/field	0.313	0.190
Attn/field		0.251

UFOV

	UFOV-DA	PRT	Snellen Fail
UFOV	0.861	0.678	0.215
UFOV-DA		0.251	0.166
PRT			0.111

Note. Results are for all age groups combined. All Pearson Correlation Coefficients are statistically significant (p<.0001).

APPENDIX D

Summary of the Hierarchical Multiple Regression Equations Indicating the Moderating Effect of Self-Restriction

	Significance (p) level	Unstandardized regression estimate	Standardized regression coefficient
AGES 26-39			
Snellen Fail			
VISION	0.004	0.276	0.094
VISION X DRIVING ALONE	0.010	-0.395	-0.085
F for the model = 2.937, p = 0.003, N = 966, Adj Multiple R^2 = 0.016, R^2 Increment>.01 = 0.010			
VISION	0.023	0.243	0.082
VISION X DRIVING ALONE	0.027	-0.516	-0.111
VISION X AGE	0.612	-0.016	-0.018
DRIVING ALONE X AGE	0.842	0.002	0.007
VISION X DRIVING ALONE X AGE	0.531	-0.033	-0.031
F for the model = 2.180, p = 0.014, N = 966, Adj Multiple R^2 = 0.013, R^2 Increment>.01 = 0.011			
Pelli-Robson Low-Contrast Acuity Loss			
VISION	0.381	0.013	0.047
VISION X AVOIDANCE	0.002	-0.019	-0.170
F for the model = 3.942, p = 0.000, N = 333, Adj Multiple R^2 = 0.066, R^2 Increment>.01 = 0.033			
VISION	0.356	0.014	0.049
VISION X AVOIDANCE	0.002	-0.020	-0.173
VISION X AGE	0.008	-0.012	-0.145
AVOIDANCE X AGE	0.031	0.007	0.115
VISION X AVOIDANCE X AGE	0.035	-0.004	-0.118
F for the model = 4.374, p = 0.000, N = 333, Adj Multiple R^2 = 0.101, R^2 Increment>.01 = 0.075			
Skill-Card High Contrast Near Acuity Loss			
VISION	0.750	0.005	0.019
VISION X HEAVY TRAFFIC	0.004	-0.059	-0.170
F for the model = 3.511, p = 0.001, N = 339, Adj Multiple R^2 = 0.056, R^2 Increment>.01 = 0.032			
VISION	0.754	0.005	0.018
VISION X HEAVY TRAFFIC	0.000	-0.076	-0.220
VISION X AGE	0.988	0.000	0.001
HEAVY TRAFFIC X AGE	0.020	0.024	0.127
VISION X HEAVY TRAFFIC X AGE	0.090	0.013	0.108
F for the model = 3.322, p = 0.000, N = 339, Adj Multiple R^2 = 0.070, R^2 Increment>.01 = 0.054			

Note. The model term 'VISION' refers to the vision test score bolded at the beginning of the section. In addition to the underlined predictor variables, each equation included the following covariates: Age, Gender, Age x Gender, Hrs/wk driving, Miles/wk driving, and Self-restriction. The form of self-restriction was the same as that in the vision by self-restriction interaction term. In the two cases where more than one form of self-restriction moderated VTP, the results of the model are shown which specified the composite self-restriction term, AVOIDANCE. Incremental explained variance greater than 1% (R^2 increment>.01) is due to adding the underlined predictor variables to the above indicated covariates. In order to minimize multicollinearity, all the independent variables were centered (Cronbach, 1987; Jaccard, Turrisi & Wan, 1990).

APPENDIX D-2

	Significance (p) level	Unstandardized regression estimate	Standardized regression coefficient
AGES 26-39 (continued)			
Skill-Card Low Contrast Near Acuity Loss			
VISION	0.258	-0.006	-0.062
VISION X HEAVY TRAFFIC	0.028	-0.015	-0.120
F for the model = 2.762, p = 0.006, N = 339, Adj Multiple R^2 = 0.040, R^2 Increment>.01 = 0.016			
VISION	0.330	-0.005	-0.053
VISION X HEAVY TRAFFIC	0.009	-0.018	-0.145
VISION X AGE	0.838	0.000	0.012
HEAVY TRAFFIC X AGE	0.042	0.021	0.112
VISION X HEAVY TRAFFIC X AGE	0.072	0.004	0.104
F for the model = 2.667, p = 0.003, N = 339, Adj Multiple R^2 = 0.052, R^2 Increment>.01 = 0.036			
AGES 40-51			
Pelli-Robson Low Contrast Acuity Loss			
VISION	0.623	0.007	0.030
VISION X AVOIDANCE	0.037	-0.012	-0.126
F for the model = 1.630, p = 0.116, N = 305, Adj Multiple R^2 = 0.016, R^2 Increment>.01 = 0.014			
VISION	0.650	0.007	0.028
VISION X AVOIDANCE	0.054	-0.011	-0.120
VISION X AGE	0.952	-0.000	-0.004
AVOIDANCEX AGE	0.609	-0.001	-0.032
VISION X AVOIDANCE X AGE	0.988	-0.000	-0.010
F for the model = 1.202, p = 0.285, N = 305, Adj Multiple R^2 = 0.007, R^2 Increment>.01 = 0.015			
AGES 70+			
Pelli-Robson Low Contrast Acuity Loss			
VISION	0.299	0.007	0.062
VISION X HEAVY TRAFFIC	0.060	-0.014	-0.105
F for the model = 1.704, p = 0.097, N = 325, Adj Multiple R^2 = 0.017, R^2 Increment>.01 = 0.014			
VISION	0.435	0.005	0.046
VISION X HEAVY TRAFFIC	0.008	-0.022	-0.160
VISION X AGE	0.001	0.004	0.194
HEAVY TRAFFIC X AGE	0.056	0.012	0.116
VISION X HEAVY TRAFFIC X AGE	0.480	-0.001	-0.044
F for the model = 2.491, p = 0.005, N = 325, Adj Multiple R^2 = 0.048, R^2 Increment>.01 = 0.053			

APPENDIX D-3

	Significance (p) level	Unstandardized regression estimate	Standardized regression coefficient
AGES 70+			
Standard Field Integrity Loss			
VISION	0.115	0.010	0.091
VISION X LEFT TURNS	0.018	0.017	0.137
F for the model = 3.042, p = 0.003, N = 304, Adj Multiple R^2 = 0.051, R^2 Increment>.01 = 0.027			
VISION	0.910	-0.001	-0.007
VISION X LEFT TURNS	0.505	0.005	0.043
VISION X AGE	0.193	0.002	0.086
LEFT TURNS X AGE	0.323	0.003	0.057
VISION X LEFT TURNS X AGE	0.011	0.004	0.175
F for the model = 3.340, p = 0.000, N = 304, Adj Multiple R^2 = 0.078, R^2 Increment>.01 = 0.063			
Attentional Field Integrity Loss			
VISION	0.392	0.001	0.050
VISION X LEFT TURNS	0.000	0.004	0.193
F for the model = 3.804, p = 0.000, N = 305, Adj Multiple R^2 = 0.069, R^2 Increment>.01 = 0.044			
VISION	0.707	0.000	0.021
VISION X LEFT TURNS	0.051	0.002	0.113
VISION X AGE	0.008	0.001	0.152
LEFT TURNS X AGE	0.490	0.002	0.039
VISION X LEFT TURNS X AGE	0.000	0.001	0.218
F for the model = 5.205 p = 0.000, N = 305, Adj Multiple R^2 = 0.132, R^2 Increment>.01 = 0.114			
Perceptual Reaction Time			
VISION	0.003	0.001	0.179
VISION X LEFT TURNS	0.010	0.001	0.154
F for the model = 2.413, p = 0.016, N = 277, Adj Multiple R^2 = 0.039, R^2 Increment>.01 = 0.052			
VISION	0.006	0.001	0.192
VISION X LEFT TURNS	0.001	0.002	0.217
VISION X AGE	0.046	-0.000	-0.133
LEFT TURNS X AGE	0.147	-0.009	-0.088
VISION X LEFT TURNS X AGE	0.771	-0.000	-0.020
F for the model = 2.414 p = 0.007, N = 277, Adj Multiple R^2 = 0.053, R^2 Increment>.01 = 0.075			

APPENDIX E

Summary of the Hierarchical Multiple Regression Equations Indicating VTP is More Strongly Associated with Crashes when the Subject has Failed the Department's Snellen Test (Marked by Asterisk)

	Significance (p) level	Unstandardized regression estimate	Standardized regression coefficient
Pelli-Robson Contrast Sensitivity Loss			
Intercept	0.000	0.177	0.000
Age	0.525	0.001	0.030
Gender	0.427	-0.020	-0.024
Age x gender	0.055	-0.003	-0.076
Hrs/wk driving	0.823	0.000	0.007
Miles/wk driving	0.003	0.000	0.101
Snellen Fail (SF)	0.215	-0.076	-0.050
VISION	0.677	0.002	0.018
VISION X SF	0.105	0.019	0.070
F for the model	2.686		
p	0.006		
N	1,194		
Adj Multiple R^2	0.011		
R^2 Increment>.01			
Intercept	0.000	0.185	0.000
Age	0.597	0.001	0.026
Gender	0.470	-0.018	-0.021
Age x gender	0.057	-0.003	-0.075
Hrs/wk driving	0.796	0.001	0.008
Miles/wk driving	0.003	0.000	0.100
Snellen Fail (SF)	0.204	-0.081	-0.053
VISION	0.450	0.005	0.037
VISION X SF	0.589	-0.011	-0.042
VISION X AGE	0.351	-0.000	-0.038
SF X AGE	0.287	-0.004	-0.059
VISION X SF X AGE*	0.020	0.002	0.189
F for the model	2.458		
p	0.005		
N	1,194		
Adj Multiple R^2	0.013		
R^2 Increment>.01			

Note. The model term 'VISION' refers to the vision test score bolded at the beginning of the section. Incremental explained variance greater than 1% (R^2 increment>.01) is due to adding the underlined predictor variables to the model. In order to minimize multicollinearity, all the independent variables were centered (Cronbach, 1987, Jaccard, Turrisi & Wan, 1990).

Appendix E-2

	Significance (p) level	Unstandardized regression estimate	Standardized regression coefficient
SKILL-Card Low Contrast Near Acuity Loss			
Intercept	0.000	0.181	0.000
Age	0.520	0.001	0.031
Gender	0.299	-0.026	-0.031
Age x gender	0.075	-0.003	-0.070
Hrs/wk driving	0.812	0.000	0.008
Miles/wk driving	0.004	0.000	0.096
Snellen Fail (SF)	0.210	-0.075	-0.049
VISION	0.994	-0.000	-0.000
VISION X SF	0.071	0.006	0.077
F for the model	2.654		
p	0.007		
N	1,200		
Adj Multiple R^2	0.011		
R^2 Increment>.01			
Intercept	0.000	0.183	0.000
Age	0.474	0.001	0.360
Gender	0.369	-0.023	-0.267
Age x gender	0.060	-0.003	-0.074
Hrs/wk driving	0.773	0.001	0.009
Miles/wk driving	0.004	0.000	0.096
Snellen Fail (SF)	0.060	-0.121	-0.079
VISION	0.974	0.000	0.001
VISION X SF	0.768	-0.002	-0.020
VISION X AGE	0.614	-0.000	-0.019
SF X AGE	0.241	-0.005	-0.065
VISION X SF X AGE*	0.003	0.001	0.205
F for the model	2.845		
p	0.001		
N	1,200		
Adj Multiple R^2	0.017		
R^2 Increment>.01	0.011		

Appendix E-3

	Significance (p) level	Unstandardized regression estimate	Standardized regression coefficient
BGT Low Contrast Near Acuity Loss			
Intercept	0.000	0.180	0.000
Age	0.672	0.001	0.019
Gender	0.301	-0.026	-0.031
Age x gender	0.081	-0.003	-0.068
Hrs/wk driving	0.834	0.000	0.007
Miles/wk driving	0.003	0.000	0.098
Snellen Fail (SF)	0.141	-0.083	-0.054
VISION	0.637	0.001	0.020
VISION X SF*	0.034	0.009	0.087
F for the model	3.134		
p	0.002		
N	1,199		
Adj Multiple R^2	0.014		
R^2 Increment>.01			
Intercept	0.000	0.187	0.000
Age	0.789	0.000	0.013
Gender	0.398	-0.021	-0.025
Age x gender	0.072	-0.003	-0.071
Hrs/wk driving	0.821	0.000	0.007
Miles/wk driving	0.003	0.000	0.098
Snellen Fail (SF)	0.046	-0.127	-0.082
VISION	0.367	0.002	0.044
VISION X SF	0.432	-0.006	-0.055
VISION X AGE	0.267	-0.000	-0.044
SF X AGE	0.344	-0.003	-0.045
VISION X SF X AGE*	0.003	0.001	0.225
F for the model	3.087		
p	0.000		
N	1,199		
Adj Multiple R^2	0.019		
R^2 Increment>.01	0.013		

Appendix E-4

	Significance (p) level	Unstandardized regression estimate	Standardized regression coefficient
BGT Low Contrast Near Acuity Loss in the Presence of Glare			
Intercept	0.000	0.180	0.000
Age	0.536	0.001	0.031
Gender	0.309	-0.026	-0.030
Age x gender	0.086	-0.003	-0.067
Hrs/wk driving	0.827	0.000	0.007
Miles/wk driving	0.003	0.000	0.098
Snellen Fail (SF)	0.289	-0.060	-0.039
VISION	0.981	-0.000	-0.001
VISION X SF	0.106	0.004	0.069
F for the model	2.668		
p	0.007		
N	1,199		
Adj Multiple R^2	0.011		
R^2 Increment>.01			
Intercept	0.000	0.181	0.000
Age	0.607	0.001	0.027
Gender	0.411	-0.021	-0.024
Age x gender	0.099	-0.002	-0.065
Hrs/wk driving	0.804	0.001	0.008
Miles/wk driving	0.003	0.000	0.098
Snellen Fail (SF)	0.115	-0.100	-0.065
VISION	0.884	0.000	0.008
VISION X SF	0.391	-0.004	-0.069
VISION X AGE	0.674	-0.000	-0.018
SF X AGE	0.557	-0.002	-0.031
VISION X SF X AGE*	0.014	0.001	0.201
F for the model	2.541		
p	0.004		
N	1,199		
Adj Multiple R^2	0.014		
R^2 Increment>.01			

Appendix E-5

	Significance (p) level	Unstandardized regression estimate	Standardized regression coefficient
Visual Attention Analyzer UFOV Loss			
Intercept	0.000	0.159	0.000
Age	0.016	-0.003	-0.114
Gender	0.785	-0.007	-0.008
Age x gender	0.719	0.001	0.014
Hrs/wk driving	0.035	0.005	0.071
Miles/wk driving	0.818	0.000	0.008
Snellen Fail (SF)	0.424	0.035	0.026
VISION	0.063	0.002	0.075
VISION X SF	0.337	0.002	0.034
F for the model	2.350		
p	0.017		
N	1,197		
Adj Multiple R^2	0.009		
R^2 Increment>.01	0.016		
Intercept	0.000	0.157	0.000
Age	0.211	-0.002	-0.062
Gender	0.752	-0.008	-0.009
Age x gender	0.723	0.001	0.014
Hrs/wk driving	0.031	0.005	0.072
Miles/wk driving	0.842	0.000	0.007
Snellen Fail (SF)	0.003	0.171	0.129
VISION	0.361	0.001	0.039
VISION X SF*	0.006	0.016	0.260
VISION X AGE	0.702	0.000	0.014
SF X AGE	0.000	-0.013	-0.198
VISION X SF X AGE	0.091	-0.000	-0.156
F for the model	3.194		
p	0.000		
N	1,197		
Adj Multiple R^2	0.020		
R^2 Increment>.01	0.029		

Appendix E-6

	Significance (p) level	Unstandardized regression estimate	Standardized regression coefficient
Visual Attention Analyzer Perceptual Reaction Time			
Intercept	0.000	0.156	0.000
Age	0.071	-0.002	-0.075
Gender	0.960	-0.001	-0.001
Age x gender	0.607	0.001	0.020
Hrs/wk driving	0.027	0.005	0.074
Miles/wk driving	0.875	0.000	0.005
Snellen Fail (SF)	0.394	0.035	0.026
VISION	0.474	0.000	0.025
VISION X SF*	0.026	0.002	0.079
F for the model	2.796		
p	0.005		
N	1,197		
Adj Multiple R^2	0.012		
R^2 Increment>.01	0.019		
Intercept	0.000	0.159	0.000
Age	0.308	-0.001	-0.044
Gender	0.926	-0.002	-0.003
Age x gender	0.536	0.001	0.024
Hrs/wk driving	0.025	0.005	0.075
Miles/wk driving	0.843	0.000	0.007
Snellen Fail (SF)	0.002	0.167	0.126
VISION	0.548	0.000	0.021
VISION X SF*	0.002	0.010	0.483
VISION X AGE	0.699	-0.000	-0.016
SF X AGE	0.000	-0.010	-0.148
VISION X SF X AGE*	0.015	-0.000	-0.379
F for the model	3.493		
p	0.000		
N	1,197		
Adj Multiple R^2	0.022		
R^2 Increment>.01	0.031		